SOURCE, COMPOSITION, AND FLUX OF ORGANIC DETRITUS IN LOWER COOK INLET

by

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1. ABSTRACT

A series of sediment trap deployments was combined with intensive water column sampling to obtain measurements of the production and input of organic detritus to the sea floor in relation to the bio-physical environments of lower Cook Inlet. During four of five one-week cruises from March through August, 1978, three sediment-trap arrays were deployed in environmentally distinct areas of the lower Inlet. The samples provided measurements of downward fluxes of total particulate matter; organic carbon and nitrogen; chlorophyll a and pheophorbide a; fecal pellets; and other microscopically identifiable particles including phytoplankton cells, crustacean molts, and microzooplankton. Total particulate fluxes measured by use of sediment traps were in good agreement with rates of average accumulation of sediments determined by Pb-210 dating. Total particulate fluxes measured by use of sediment traps were in good agreement with rates of average accumulation of sediments determined by Pb-210 dating. Total particulate fluxes ranged between 72 g/m2day in an area and season of high runoff to 1.9 g/m^2day in the central Inlet where upwelling of clear water is evident.

The measurements of pigment content in sediment-trap material and in the overlying euphotic zone permitted us to calculate the percent of phytoplankton stock lost to the bottom per day, and the fraction of that loss which was grazed by zooplankton. The average daily loss of phytoplankton material to the bottom was about 5-8%, of which about 83% was attributed to grazing and subsequent fecal pellet production.

Comparisons of organic carbon and nitrogen content (dry-weight percent) of the sediment trap samples among the three sampling locations generally reflected the primary productivity in overlying waters. Kachemak Bay (eastern Inlet) samples averaged 2.8% carbon compared with an average of 1.3% in the central Inlet and Kamishak Bay (western Inlet). Similar comparisons for nitrogen were 0.36% at Kachemak Bay and 0.15% at the other locations. Very high primary productivity (as high as 7.8 g C/m^2day) persisted over several months at Kachemak Bay, which accounted for the larger proportion or organic carbon and nitrogen. The total supplies of organic carbon to the bottom over the four-month study were 60 g C/m^2 at Kachemak Bay, 17 g C/m^2 in central Inlet, and 40 g C/m^2 in Kamishak Bay. These values account for approximately 12% of the total primary production over the same period.

These results indicate the transfer of substantial organic matter (which presumably is a needed nutrition source for the benthos) from surface waters to the benthos, much of it via zooplankton fecal pellets. Such particles, if contaminated with oil, act as transfer agents for oil from the surface thus impacting the benthic community.

II. INTRODUCTION

The organic detrital program conducted in lower Cook Inlet for OCSEAP was designed to provide insight into the sources, composition, and vertical fluxes of organic particles contributed to the benthic food web. A series of sediment trap deployments was combined with intensive water column sampling to obtain measurement of the production and input of organic detritus to the sea floor in relation to the bio-physical environments of lower Cook Inlet.

The region of study is extremely rich in commercially harvested populations of snow, king, and Dungeness crabs, shrimp, razor clams, and scallops (BLM 1976) . Such benthic organisms are potentially vulnerable to contamination by accidental oil spills and chronic low-level pollution associated with petroleum development in lower Cook Inlet. The larval stages of these and other benthic species are planktonic and rely directly or indirectly on phytoplankton as their food source. Adults in the benthic community ultimately depend on organic production in the overlying waters to supply their nutritional requirements. Phytoplankton grazed by zooplankton enters the detrital food web via fecal pellet production and deposition. Whole cells may also reach the benthos directly by sinking.

When oil enters seawater, emulsions of tiny droplets can adsorb onto suspended particles, become entrained in the water column, and ultimately be deposited on the bottom. The process is one of initial adsorption, followed by flocculation of oil-sediment emulsions by electrostatic interactions (Bassin and Ichiye 1977). These oil-particulate aggregates are distributed throughout the water column as sinking particles (Forrester 1971). The quantity of oil that can be sedimented by a given amount of suspended matter is dependent on the physical-chemical nature of the particles as well as the amount of naturally occurring organic matter associated with the particles (Poirier and Thiel 1941, Meyers and Quinn 1973). Laboratory studies using mixtures of Cook Inlet sediments and crude oil indicated that a maximum amount of oil equal to 11% of the sediment weight could be accommodated by particles in suspension (Feely et al. 1978). Oil coated onto the surface of particles is one of the principal ways in which petroleum contaminants may be ingested by marine organisms (NAS 1975). Following the wreck of the tanker Arrow, Conover (1971) found that zooplankton

could consume up to 20% of the oil particles smaller than 1 mm in diameter and sediment them as fecal material. Parker (1970) also reported that copepods and barnacle larvae incorporated oil into fecal pellets. Thus, sorption and ingestion may act as precipitation mechanisms to transfer otherwise buoyant oil particles to the detrital food web.

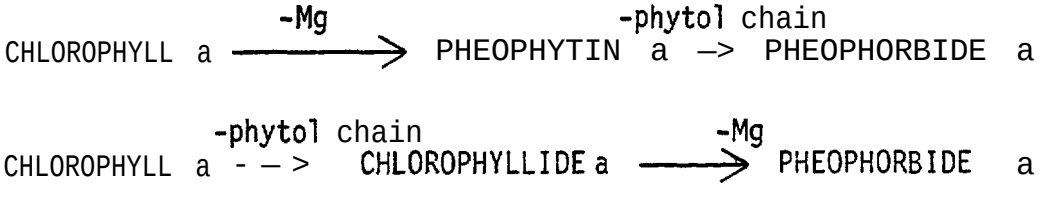
The overall purpose of the present study was to define the seasonal composition and fluxes of organic detritus in relation to the phytoplankton standing stock and productivity of lower Cook Inlet. A major emphasis has been placed on the use of plant pigments as tracer molecules to estimate the daily contribution of phytoplankton to the sea floor. Phytoplankton material can reach the bottom in two important ways:

a. cells may sink directly,

b. cells may be ingested by zooplankton, metabolically processed, repackaged, and eliminated as fecal material.

Smayda (1970) reviewed the literature and reported highly variable sinking rates for phytoplankton cells (0-30 m day^{-1}) depending on cell buoyancy, cell shape, ability to swim in response to stimuli, and nutrient concentration. It was concluded (Smayda 1971) that sinking speeds observed in the laboratory are too low to account for the apparently rapid transport of phytoplankton remains to the sea floor. He suggested that fast sinking fecal pellets (z100-200 m day^{-1}) were an explanation for this rapid transport. The importance of large particles such as fecal pellets is supported by a theoretical treatment by McCave (1975) and a rigorous field investigation by Bishop et al. (1977).

We have attempted to assess the relative importance and absolute magnitude of direct algal sinking and fecal pellet production by zooplankton grazers in lower Cook Inlet. The analysis was based on the use of chlorophyll concentration as a measure of phytoplankton abundance and on the knowledge that planktonic herbivores degrade chlorophyll to pheophorbide, an easily measured chlorophyll derivative (Currie 1962, Nemoto and Saijo 1968, Nemoto 1972, Jeffrey 1974).



Pathways of chlorophyll degradation.

The use of chlorophyll degradation products as an index of grazing pressure on phytoplankton populations was first suggested by Lorenzen (1967). Mackas and Bohrer (1976) investigated the diel feeding patterns of zooplankton by analyzing their gut contents for degraded chlorophyll pigments. A laboratory study by Shuman and Lorenzen (1975) demonstrated that grazed chlorophyll was totally converted to pheophorbide on a mole for mole basis. This knowledge was used (Shuman 1978) to estimate grazing and sinking losses from phytoplankton populations during a Puget Sound sediment trap study.

A similar approach was followed during the present Cook Inlet study. A conceptual model was designed to outline and summarize the major processes considered (Fig. 1). The intent was to measure algal biomass and production in the water column and relate it to the fluxes of chlorophyll, pheophorbide, organic carbon, nitrogen, and fecal pellets, whole phytoplankton cells, and other discrete particles sinking to the sea bed.

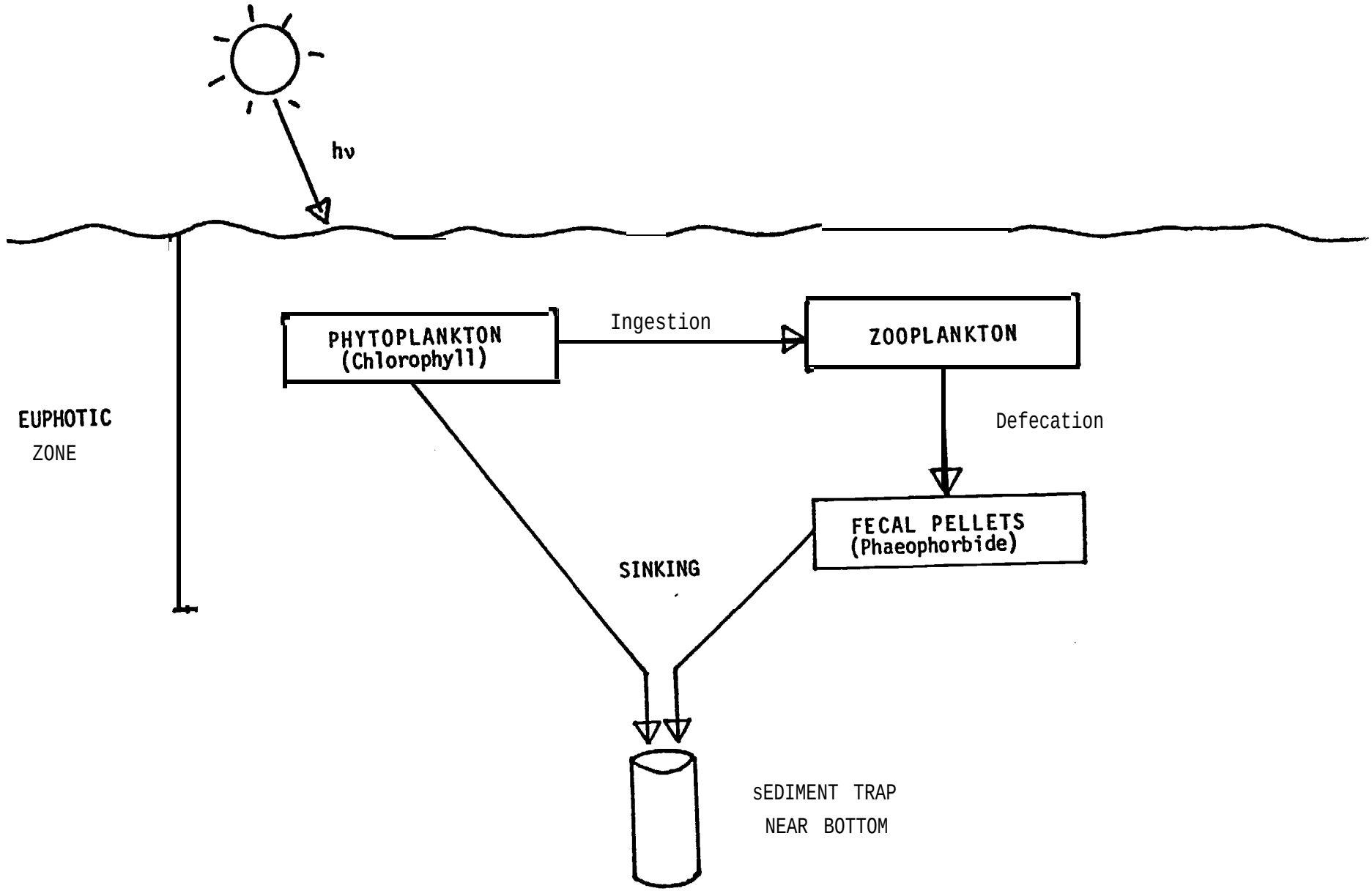
III. CURRENT STATE OF KNOWLEDGE AND STUDY AREA

The circulation of lower Cook Inlet is a primary determinant of the basic biological productivity of the system. It supplies plant nutrients; provides gyres which act as "traps" for development of abundant plankton populations; carries large loads of suspended particles which attenuate light and primary production; and mixes water vertically to remove phytoplankton from the euphotic zone or, alternatively, relaxes mixing to permit stratification of the water column and maintain phytoplankton in the euphotic zone.

A. Circulation and Physical Characteristics

Descriptions of various aspects of the physical oceanography of Cook Inlet appear in several publications and reports (cf. Knull and Williamson, 1969; Kinney, et al., 1970; Evans, et al., 1972; Gatto, 1976; Burbank, 1977; and Muench, et al., 1978). Cook Inlet is a positive tidal estuary approximately 350 km long by 80-90 km wide in the lower (southern) portion (Fig. 2). Mean diurnal tidal ranges are about 5-6 m in lower Cook Inlet and tidal current speeds are characteristically moderate to strong (occasionally exceeding 3m see-l). The instantaneous flow field in the lower inlet is dominated by tidal and wind-driven currents which are superposed on the mean flow as described below. Prevailing winter winds are northeasterly, and summer winds are southerly and lighter, interrupted by occasional storms, especially in late summer. Storms or other inter-

FIGURE 1. PIGMENT LOSS FROM THE EUPHOTIC ZONE AS AN INDICATION OF GRAZING.



mittent strong winds can temporarily alter the normal circulation pattern significantly.

The pattern of mean flow in the spring and summer was described by Muench, et al., 1978 (Fig. 2) and by Gatto, 1976. High-salinity (31-32%.), low-temperature (7-8.5°C) surface water from the Gulf of Alaska enters lower Cook Inlet through Kennedy Entrance at the southeast, flows westerly following bathymetry, and merges with a strong southerly flow on the western side of the inlet. Water comprising this southerly flow during the summer is characterized by lower salinity (29-31%.), higher temperature (8-11°C) and large concentrations of suspended particles which are carried south from the upper inlet. Weaker northerly currents occur in the eastern and central portions of the lower inlet and bend westward across the axis of the inlet to join the southerly flow. Water in the eastern and central inlet originates in the Gulf of Alaska, enters through Kennedy Entrance with the strong westward component, and branches northward.

Data presented by Knull and Williamson (1969) suggest a gyre system in outer Kachemak Bay. Spring and summer circulation in outer Kachemak Bay was studied by Burbank (1977) who used drogues and described two counter rotating gyres which occur part of the time. A large clockwise gyre was observed in the western half of the outer bay and a slightly smaller counter clockwise gyre occurred in the eastern half. Water is exchanged around the entire perimeter of the gyres but consists primarily of gulf water from the south and loss of water to the north. The latter contains fresh water at the surface originating from runoff in inner Kachemak Bay and forms a current flowing northwestward along the northeast coast. Burbank (1977) estimated residence time of water in outer Kachemak Bay to be as long as 15 days. Knull and Williamson (1969) estimated a flushing time for the entire Kachemak Bay of 27 days based on salinity and river runoff which is in reasonably good agreement with Burbank's estimate of residence time. This relatively long residence time of water is a factor which contributes to the development of a large spring and summer phytoplankton population in outer Kachemak Bay. In contrast, adjacent areas to the west where water is more thoroughly mixed, populations are diluted and displaced from the system rather rapidly.

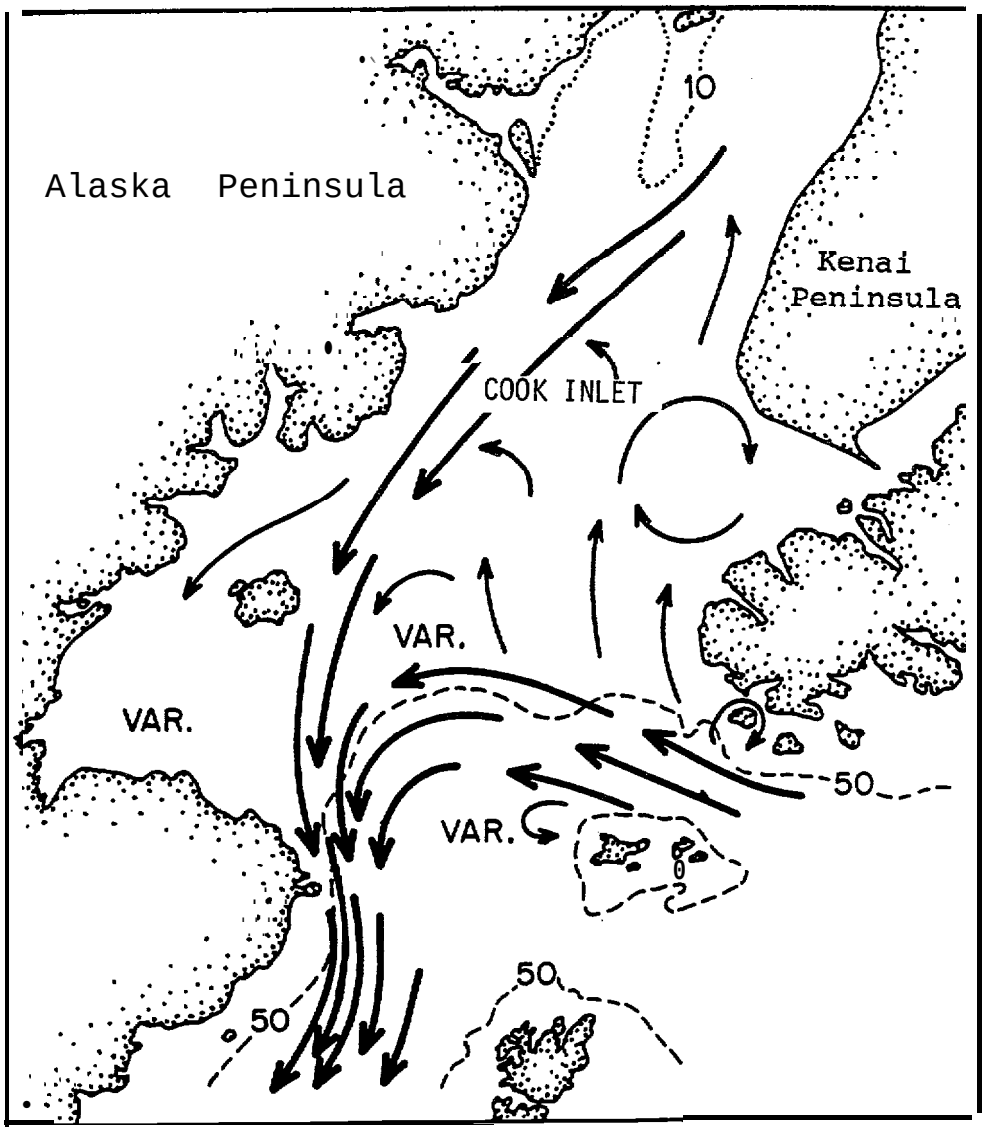


Figure 2. Diagram of spring and summer mean flow in lower Cook Inlet (after Muench, et al., 1978).

Another feature of the Cook Inlet environment of importance to biological production is the heavy load of suspended matter which is transported southward from the upper inlet. Approximately the western third of the lower inlet contains highly turbid, low salinity water in spring and summer, a characteristic that has been well documented by Evans, et al. (1972); Gatto (1976); Larrance et al. (1977); and Feely, et al. (1978). Feely, et al. (1978) reported concentrations of total suspended matter as high as 8 mg l^{-1} near Kamishak Bay and 100 mg l^{-1} south of the forelands. Larrance, et al. (1977) measured euphotic zone depths (depth to which 1% of the incident light penetrates) of less than 1 m south of the forelands. Such highly turbid water severely restricts primary productivity in the western and northern portions of lower Cook Inlet.

B. Phytoplankton and Primary Production

Knull and Williamson (1969) surveyed net phytoplankton in Kachemak Bay in April, July and October. In the outer bay, *Fragilaria* and *Thalassiosira* were dominant in April, being replaced by *Chaetoceros* in July, especially *C. debilis*. In late October *Chaetoceros decipiens*, *Schroderella delicatula*, and *Coscinodiscus* spp. shared dominance at outer bay stations. This general pattern was similar to that reported by Larrance, et al. (1977). Microflagellates were included in the latter report but not in Knull and Williamson's data because water bottles instead of nets were used for sampling. Microflagellates were ubiquitous and ranked among the two or three most numerous groups of organisms in lower Cook Inlet during spring and summer, 1976. In terms of diatoms, there was a sequence of dominance starting with several *Thalassiosira* species (especially *T. aestivalis*) forming the initial spring bloom, followed by *Chaetoceros* (especially *C. debilis*) in July. This sequence began first in Kachemak Bay in early May and seemed to progress westward across the lower inlet, so that the *Thalassiosira-Chaetoceros* sequence in Kamishak Bay lagged about a month behind Kachemak Bay. The highest cell concentrations reported were on the order of 10^6 cells l^{-1} of *Thalassiosira* in Kachemak Bay in early May.

A more or less classical seasonal pattern of primary productivity for temperate waters was documented in the lower inlet by Larrance, et al. (1977). Large increases from April to July in primary productivity and phytoplankton

standing stocks were accompanied by declining nutrients" (especially nitrate) and increasing incident light. Production was apparently light-limited before April, and became somewhat nutrient-limited in July in some areas, particularly in Kachemak Bay. Maximum productivity at locations along a cross-inlet section between Kachemak and Kamishak Bays occurred sequentially from east to west as with the species succession. Productivity maxima occurred in Kachemak Bay in early May, in mid-inlet in late May and in Kamishak Bay in July. The large amount of non-living suspended particles on the western side of the inlet probably delayed the phytoplankton bloom in Kamishak Bay, and advection (including upwelling described by Muench, et al., 1978) prevented the buildup of large populations in the middle of the inlet. The relationship between productivity and turbidity was discussed by Larrance, et al. (1977) and was inferred from correlation between productivity and light transmittance measurements. There was an increase of productivity with an increase in light transmission (assumed to coincide with fewer suspended particles).

Iv. FIELD AND LABORATORY METHODS

A. Field Schedule and Strategy

Five cruises to lower Cook Inlet were conducted between March and August 1978. The overall project aim was to determine vertical fluxes and composition of organic detritus and to relate these to regional differences in the primary production and standing stock of phytoplankton in lower Cook Inlet. During each cruise a cross-inlet transect consisting of seven stations was sampled to obtain physical, chemical, and biological information from the water column. In addition to this transect, a grid of closely spaced stations was occupied in Kachemak Bay during four of the cruises to monitor finer scaled environmental variability. On the last four cruises dual sediment traps of PMEL design were deployed at three stations and retrieved after approximately five days.

1. NOAA Ship Schedule

Cruises were conducted according to the following schedule:

Dates	Vessel	NOS	PMEL
March 23-27	SURVEYOR	RP-4-SU-78-A	LC1781
May 7-14	MILLER FREEMAN	RP-4-MF-78A I	LC1782
June 6-13	MILLER FREEMAN	RP-4-MF-78A III	LC1783
July 12-20	MILLER FREEMAN	RP-4-MF-78A V	LC1784
August 13-20	SURVEYOR	RP-4-SU-78B	LC1785

* Numbers assigned for internal PMEL use. These numbers will be used in the text of this report.

2. Station Locations

Seven stations (Fig. 3) were routinely occupied each day except for the first and last days of each cruise when sediment traps were deployed and recovered. These stations were spaced at intervals of about 18 km across the inlet between Kamishak Bay and Kachemak Bay. In addition, a grid of closely spaced stations in the Kachemak Bay area was occupied on all cruises except LC1781. The nominal locations for stations 1-7 are given below:

Station	Latitude (N)	Longitude (W)
1	59° 14.0′	153° 40.0′
2	59° 17.0′	153° 20.0′
3	59° 20.0′	153° 00.0′
4	59° 23.0′	152° 40.0′
5	59° 26.6′	152° 20.0′
6	59° 30.0′	152° 00.0′
7	59° 33.3′	151° 40.0′

The Kachemak Bay grid of stations varied in number from 8 to 18 and in the precise location depending on the cruise. All grid stations were 1-2 miles from the nearest station and centered around station 7. Plant pigments, salinity, temperature, and nutrients in the upper 25 m of water were commonly measured during the Kachemek Bay grid sampling. The grid was completed in every case within 9 hours.

B. Sediment Trap Methodology

The sediment traps and moorings were designed, fabricated, and tested in our laboratory for use during this study. Each mooring consisted of a 1700 kg steel and concrete anchor, an AMFR acoustic release, dual gimballed sediment traps, a streamlined (torpedo-shaped) subsurface float with about 500 kg buoyancy, and tethering cables, chains, and hardware (Fig. 4). Several features were incorporated into the mooring's design to reduce the effects of currents, meet sampling requirements of the study, and minimize damage to the gear of local commercial fishermen. Unusually heavy anchors were used to prevent shifting along the bottom. These anchors were smooth concrete hemispheres to reduce the chances for entanglement with fish trawls.

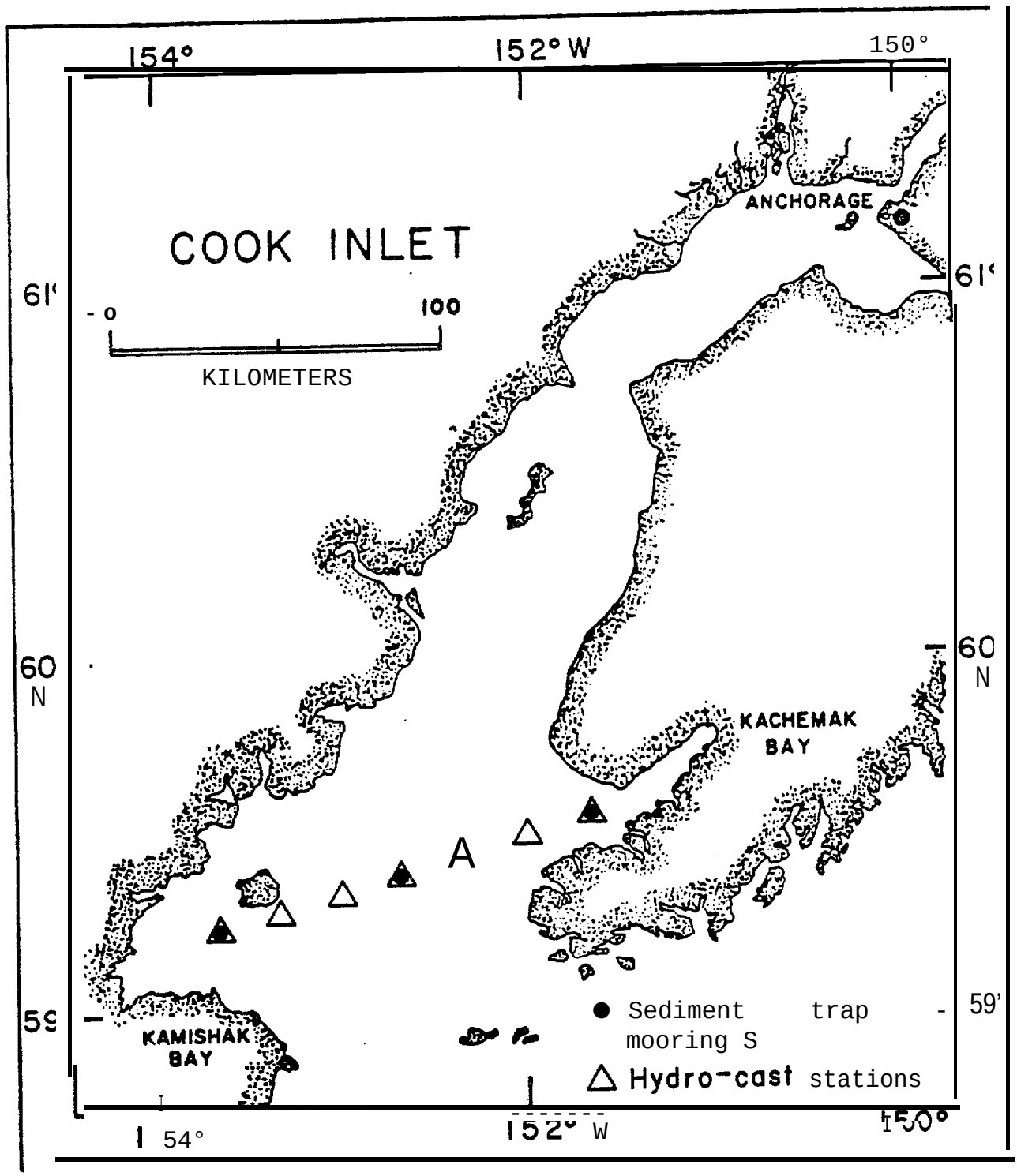


Figure 3. Station locations, lower Cook Inlet, 1978.

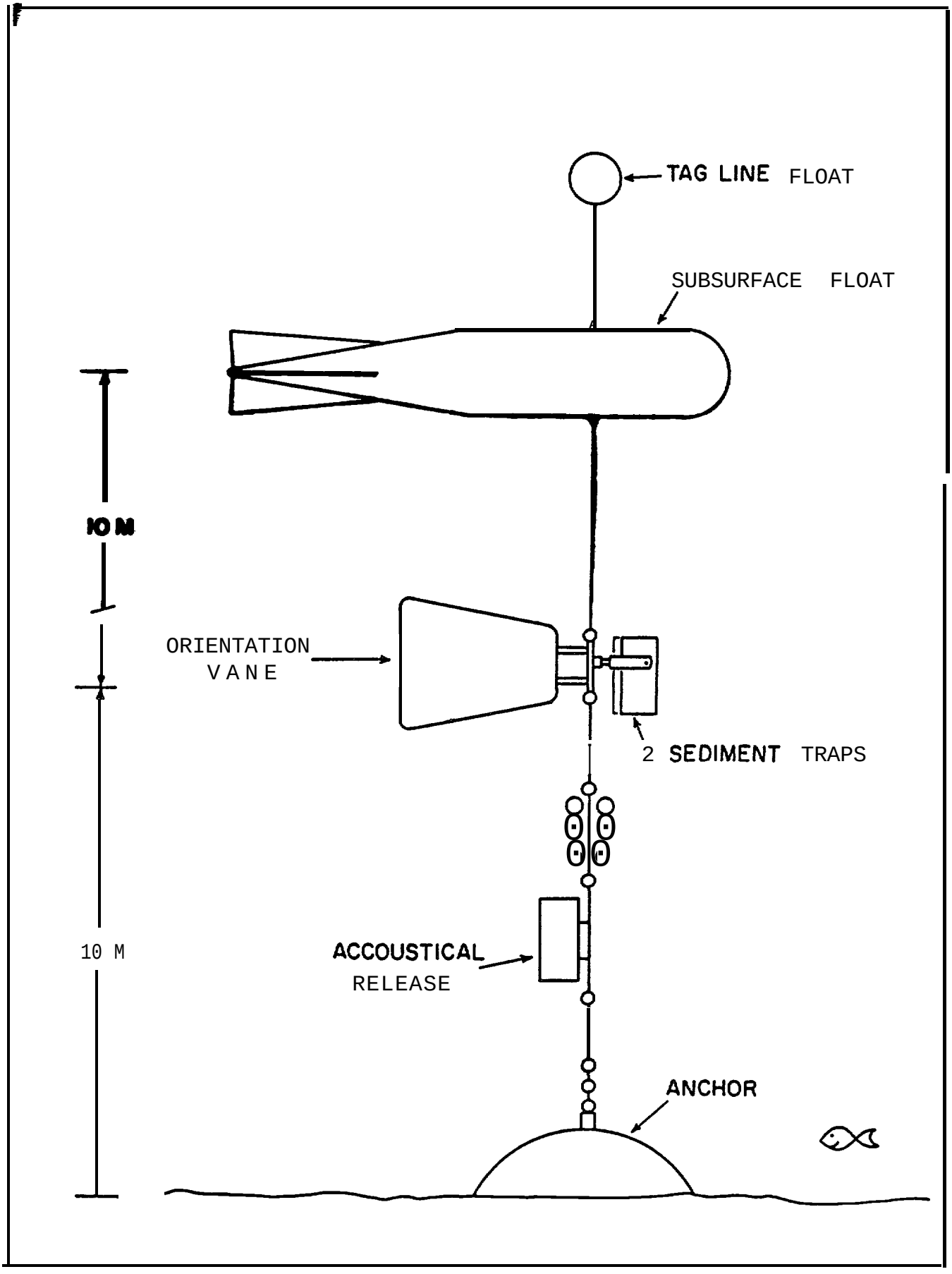


Figure 4. Sediment trap mooring, lower Cook Inlet, 1978.

Sediment traps were polyvinylchloride cylinders and each included a butterfly-valve closure actuated by a battery powered electronic timer housed in the trap casing below the sample chamber (Fig. 5). The sample chamber had a depth of approximately 40 cm and a mouth diameter of 15 cm. The aspect ratio of 2.7 corresponded well to Gardner's (1977) recommendations, and the overall dimensions were similar to those of Shuman (1978). Each trap employed a baffle across the mouth to decrease turbulent intrusions and to discourage disturbance by fish and other animals. A small cup was packed with sodium azide and mounted to the side of each trap. The azide diffused through a membrane filter into the sample compartment and provided a continuous anti-bacteriological effect.

Prior to deployment, each trap was filled with membrane filtered seawater and set in the open position with the timer activated. Surface contamination was avoided by covering the mouth with a plastic bag. This bag was held securely to the trap by rubber bands intertwined with a Morton® salt lick. The salt lick dissolved about 30 minutes after deployment and effectively opened the trap by allowing the bag to float away.

Two traps were mounted on a swivel in each mooring and gimballed to maintain the trap mouths in a horizontal plane (Fig. 5). The entire array was free to rotate about the mooring line, keeping the traps oriented upstream. This attachment method was used to provide uniform sampling unaltered by inclination of the mooring line or current direction.

Three sediment-trap moorings were deployed at the start of each cruise (except LC1781) and retrieved at theend of the cruise. Sampling times were five or six days. The deployments were made at stations 1, 4, and 7 on each cruise (Fig. 3). Sediment traps were positioned 10 m above the bottom to reduce the effect of bottom sediment resuspension. All moorings were successfully deployed and recovered throughout the study. The overall success rate for obtaining adequate samples in the traps was 63%. All the traps on the last cruise (LC1785) functioned properly and all the samples were obtained. Of twelve moorings set during the study, reliable samples were obtained from ten.

Upon recovery of the sediment traps, the sample was drained and washed into a volumetric cylinder, measured, and transferred toa 10-liter polyethylene jug. The contents of the jug were gently, but thoroughly, shaken immediately before drawing aliquot portions of the water-particle suspension for pigment, micro-

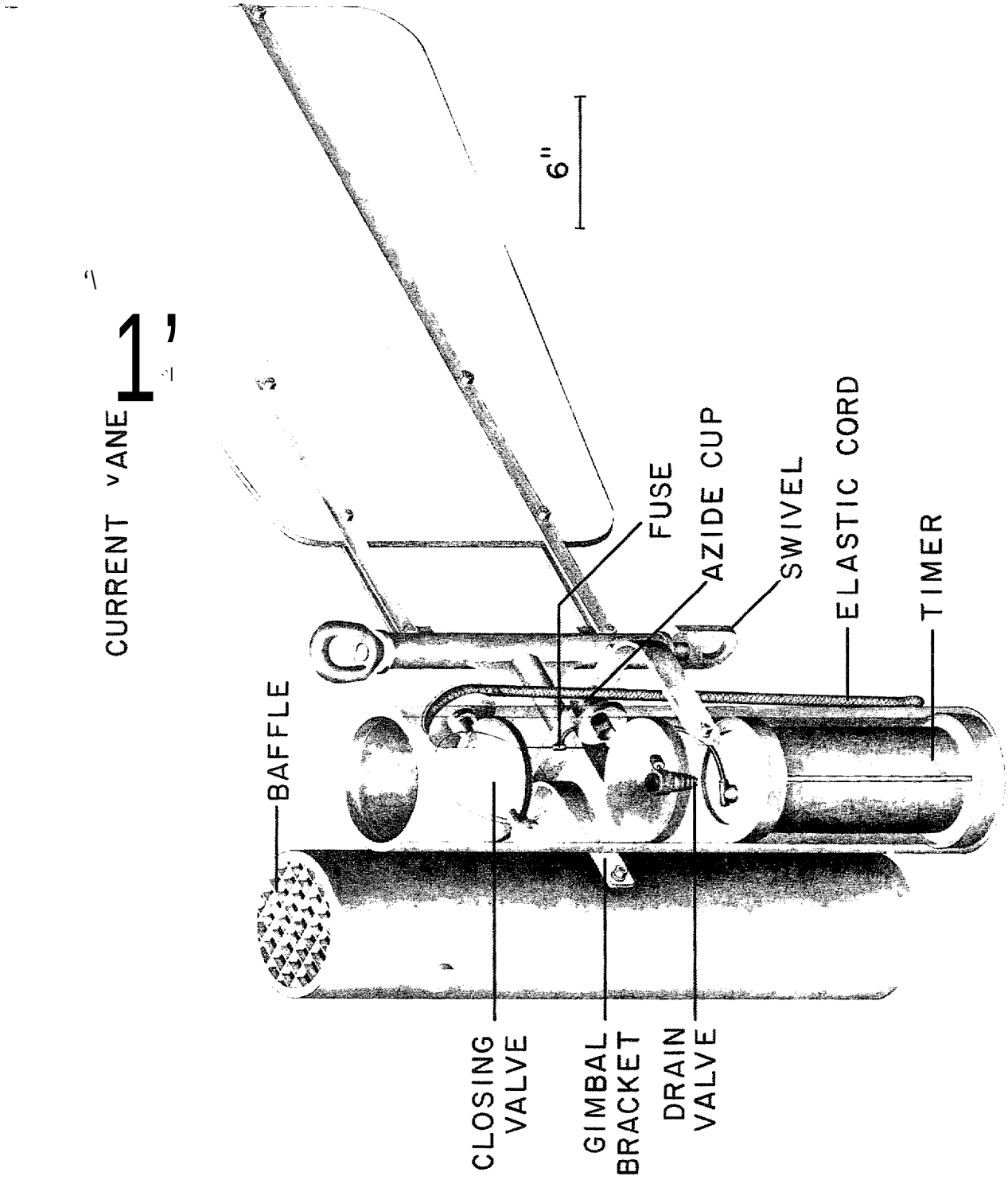


Fig. 5- Dual sediment traps with current vane, lower Cook Inlet, 1978

s.topical, and stable-isotope analyses. One subsample was taken from each sediment trap for microscopical examination, and one was taken for isotopic analysis. As many as five (depending on the sample) replicate portions of material from each nuclepore filter were analyzed for carbon and nitrogen. The pigment analyses (at least three replicates from each trap) were conducted immediately after subsampling by fluorometric methods identical to those used for chlorophyll and pheopigments in seawater (Lorenzen 1966). The subsamples for microscopical examination were preserved in a 0.6% acetate buffered formaldehyde solution and returned to Seattle for determination of numbers of fecal pellets, phytoplankton cells, zooplankton carapaces, and other identifiable particles. Large material was routinely enumerated with a dissecting microscope at 24X power. Smaller particles such as phytoplankton cells were counted with an inverted microscope at 160X power. A subsample for isotopic analysis was filtered through glass-fiber filters and returned to Seattle for analyses of stable carbon and nitrogen isotopes by mass spectrometry after combustion and conversion of organic carbon and nitrogen to $C0_2$ and N_2. The remainder of the sediment trap sample was filtered through preweighed 142 mm 0.4 m Nuclepore ® filters, washed with deionized water, dried in a desiccator, and reweighed in the laboratory to obtain the weight of total particulate matter (TPM) caught in the sediment trap. To obtain the total particulate nitrogen and carbon content (as weight-% of the TPM), portions of the material collected on the Nuclepore filter were carefully removed, weighed, and analyzed by the micro-Dumas combustion method using a Hewlett Packard C-H-N analyzer (Sharp 1974). Replicate subsamples were treated with 1N HCL and desiccated prior to C-H-N analysis to provide a measure of the organic carbon and nitrogen content of the sediments.

C. Water Sampling and Analyses

Station sampling began following deployment of sediment trap moorings. Routine CTD-rosette casts were made to obtain temperature and salinity profiles. Water samples were collected from several depths with 5-liter PVC Niskin bottles. Aliquots withdrawn from these samplers were used to measure various biological and chemical parameters. Subsamples for phytoplankton species enumeration were preserved in a 0.6% acetate buffered formaldehyde solution and returned to the laboratory for analysis by inverted microscope techniques (Lund, Kipling, and LeCren 1958). Samples for chlorophyll and pheopigment concentrations were analyzed aboard ship using fluorometric methods (Turner Fluorometer model 111) following the discrete sample technique of Lorenzen (1966). Seawater samples for determination of dissolved inorganic nutrients (nitrate, nitrite, silicate, phosphate, ammonium) were frozen and

returned to the University of Washington Department of Oceanography, where they were treated by Auto-Analyzer methods adapted from Strickland and Parsons (1972). Total particulate carbon and nitrogen were measured at stations 1, 4, and 7 once during every cruise (except LC1781). Aliquots from several depths were processed through precombusted silver filters and placed in a desiccator to await examination by C-H-N analyzer in Seattle.

Half-day primary productivity experiments were at stations 1, 4, and 7 using standard carbon-14 methodology (Strickland and Parsons 1972). Samples were taken from eight light depths ranging from 100% to 1% of surface light intensity. The exact sampling depths were chosen based on underwater quantum sensor and secchi disk readings. The quantum sensor (Lamda Instruments model LI-192S) was responsive to light in the photosynthetically active portion of the spectrum (approx. 400-700 nm). Sampling depths for sunrise incubations were selected according to previous day light profiles. Two light bottles and one dark bottle were drawn from each water bottle, inoculated with ^{14}C, and placed in a seawater-cooled incubator under comparable neutral density light screens. The carbon-14 radioactivity in the resulting samples was determined by liquid scintillation spectrometry (Packard Tricarb^{R}, model C2425). During each cruise, sunlight was continuously monitored with a quantum sensor similar to that used for underwater profiling.

v. RESULTS AND DISCUSSION

The phytoplankton and primary productivity measurements in 1978 were taken for two purposes: (1) to compare with the 1976 data for obtaining some qualitative guide to annual differences in the seasonal cycle; and (2) to supply needed information for application with sediment-trap data to determine what proportion of production in the overlying water is being transported to the vicinity of the bottom. The results presented below are limited and germane to those objectives.

A. Phytoplankton Species

The sequence of occurrence of numerically dominant phytoplankton groups near the sea surface (l-m depth) during spring and summer, 1978, was roughly similar to that in 1976 (Larrance, et al., 1977). Although microflagellates were always among the four most numerous groups in 1976, they were even more abundant in 1978 and were the most numerous group in all the samples. In

1978, their concentrations ranged between $3 \cdot 10^4$ to $3 \cdot 10^6$ cells l^{-1} which accounted for 60-99% fo total cell counts (Fig. 6). (Microflagellates were not counted, however, in samples from stations 1 and 2 for March because of interference from high concentrations of inorganic particles.) They reached their peak abundances in May and June, particularly in Kachemak Bay (station 7) when diatom blooms were also in progress.

As in 1976, the most important diatoms were *Thalassiosira* spp. and *Chaetoceros* spp. which reached peak abundances in sequence. In March, diatoms were present in low numbers ranging between a few hundred to less than 10^4 cells l^{-1}. *Thalassiosira* was among the four most-abundant groups at all stations and was top ranked at stations 2, 4 and 7 (Table 1). *Chaetoceros* was present in the middle and eastern side of the inlet in low numbers. On May 11, a large bloom of *Thalassiosira aestivalis* ($2 \cdot 10^5$ cells l^{-1}) was developed in Kachemak Bay along with about half as many *Chaetoceros* spp. At other stations the numbers of these algae were only a few percent of those at station 7. By June 8, diatom dominance in Kachemak Bay had shifted to *Chaetoceros debilis* with *Thalassiosira* reduced to about half of its May concentrations. A bloom of *Thalassiosira* was also underway in the western inlet in June, with only slightly higher *Chaetoceros* numbers than in May. By July 14, *Thalassiosira* had diminished to much lower abundances and *Chaetoceros* spp. (especially c. *debilis*) was the top ranked group at all stations in the-middle and eastern inlet. *Chaetoceros* was still very abundant in August while *Thalassiosira* was present in moderate numbers.

The pattern described was basically the same as that discerned in 1976: *Thalassiosira* blooms followed closely by *Chaetoceros* blooms. The sequence begins early (May) in Kachemak Bay and appears to spread westward.

In addition to these two dominant groups, *Melosira sulcata* appears to be an indicator of the highly turbid, less saline water flowing south from the upper inlet (Larrance, et al., 1977). In 1978, it was present primarily in the western and middle inlet which are influenced by southward flowing upper inlet water. *Cylindrotheca closterium* was more prominent in the 1978 samples than in 1976.

All species identified in the samples are listed in Table 2.

PHYTOPLANKTON CELL CONCENTRATIONS AT SURFACE
LOWER COOK INLET, 1978

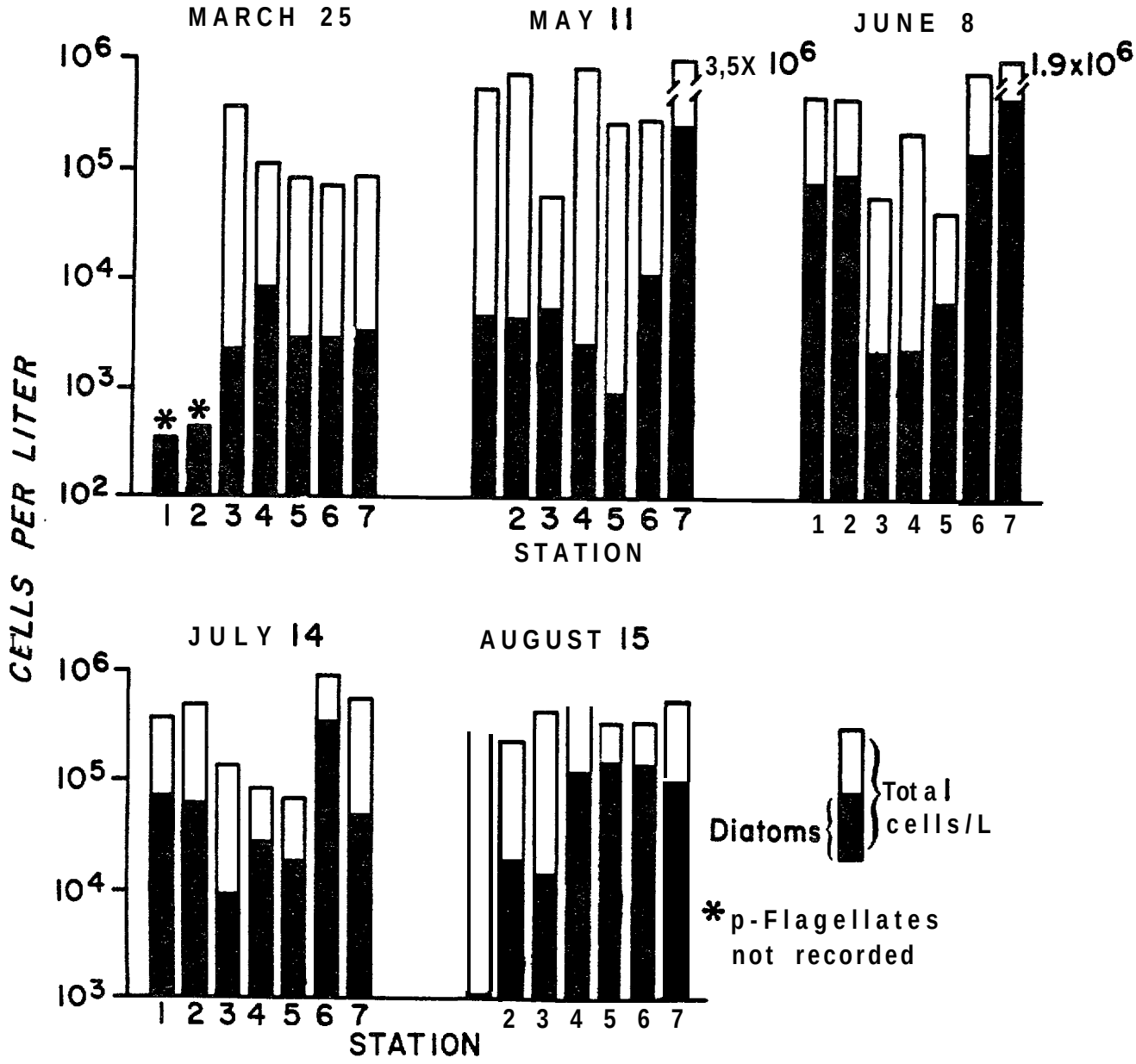


Figure 6. Surface phytoplankton cell concentrations, lower Cook Inlet, 1978.

Table 1. Important phytoplankton groups at l-m depth in lower Cook Inlet, March-August 1978. Concentrations in 10^3 cells per 1.

	Chaetoceros spp.	*Cylindrotheca closterium*	*Ditylum brightwellii*	*Melosira*	*Navicula distans*	*Nitzschia* spp.	*Thalassionema nitzschioides*	*Thalassiosira* spp.	Dinoflagellates
March 25									
1			< 0.1	0.1				0.1	
2			0.1					0.1	
3	0.2	0.1	0.3			0.7	0.3	0.3	0.2
4	1.3	1.2	0.5	0.4	0.1	0.3	1.5	3.7	0.1
5	0.1	1.6	< 0.1		0.1	0.1	0.5	0.4	0.2
6	< 0.1	0.6	< 0.1		1.2	0.2	0.3	0.2	0.1
7	0.2	1.0	< 0.1	0.2	0.2	0.2	0.3	1.1	0.3
May 11									
1			0.2	1.9			0.2	0.8	< 0.1
2	0.1	< 0.1	0.2	2.1	0.2	0.1	0.5	1.6	0.2
3	1.8		0.5				1.3	1.7	0.2
4	0.1	0.1			< 0.1			1.1	1.7
5	0.1				0.1		< 0.1	0.1	0.4
6	3.7	0.1	< 0.1		0.2	0.1	0.7	5.2	0.4
7	89.0	1.0	0.8		0.6		7.8	200.0	
June 8									
1	1.0	< 0.1	0.4		< 0.1	< 0.1	0.5	77.0	0.1
2	0.7	< 0.1	0.3	0.2			0.3	89.0	0.6
3	0.2	< 0.1	< 0.1	0.2	< 0.1		0.6	0.6	0.7
4		< 0.1		0.2	0.1		1.6	0.4	0.3
5	0.5	0.1	1.0		0.2		0.3	5.6	0.2
6	43.0		0.4		1.8	0.3	6.6	83.0	0.7
7	330.0		0.2			0.8	0.4	110.0	4.2
July 14									
1		68.0	0.1	0.1			0.8	2.0	0.1
2	2.4	7.0	31.0		< 0.1	3.4	2.9	16.0	3.2
3	7.2	0.8	< 0.1			0.3	0.3	0.2	0.3
4	22.0	< 0.1	0.3	0.1	< 0.1	0.3	1.2	2.2	0.2
5	15.0	< 0.1	0.2		< 0.1	0.3	0.7	0.8	0.1
6	310.0	4.4	0.6		2.7	2.7	5.0	1.9	0.5
7	29.0	6.9	0.1		0.3	2.0	10.0		0.7

(continued)

Table 1. (Contd.)

	Chaetoceros spp.	*Cylindrotheca closterium*	*Ditylum brightwellii*	*Melosira sulcata*	*Navicula distans*	*Nitzschia* spp.	*Thalassionema nitzschioides*	*Thalassiosira* spp.	Dinoflagellates
August 15									
1								0.1	1.1
2	4.6	5.6	0.2	0.2	< 0.1		0.1	5.4	2.0
3	1.2	2.7	0.3		< 0.1	0.4	0.2	8.3	0.2
4	88.0	1.0	0.3		0.2		6.2	25.0	0.5
5	110.0	2.2	< 0.1		0.1	0.7	14.0	7.1	0.4
6	120.0	0.2			0.3		6.8	0.2	0.2
7	80.0						0.5		1.9

Table 2. Phytoplankton species identified in near-surface water, lower Cook Inlet, 1978.

Achananthes longipes

Actinoptychus Spp.
Actinoptychus splendens
Actinoptychus undulatus

Biddulphia sp.
Biddulphia aurita

Cerataulina bergonii

Chaetoceros spp.
Chaetoceros affinis
Chaetoceros atlanticus
Chaetoceros atlanticus var. *audax*
Chaetoceros compressus
Chaetoceros concavicornis
Chaetoceros constricts
Chaetoceros crucifer
Chaetoceros danicus
Chaetoceros debilis
Chaetoceros decipiens
Chaetoceros didymus
Chaetoceros difficilis
Chaetoceros laciniosus
Chaetoceros lorenzianus
Chaetoceros pelagicus
Chaetoceros radicans
Chaetoceros secundus
Chaetoceros similis
Chaetoceros socialis
Chaetoceros teres
Chaetoceros vistulae

Cocconeis sp.
Cocconeis scutellum

Corethron hystrix

Coscinodiscus spp.
Coscinodiscus centralis var. *pacifica*
Coscinodiscus concinnus
Coscinodiscus curvatulus
Coscinodiscus lineatus
Coscinodiscus marginatus
Coscinodiscus oculus-iridis
Coscinodiscus radiatus
Coscinodiscus stellaris

Cylindrotheca closterium
Cylindrotheca fusiformis

Ditylum brightwelli

Eucampia zoodiacus

Fragillariopsis Spp.

Gyrosigma Spp.
Gyrosigma spencerii

Leptocylindrus danicus

Licmophora abbreviate

Melosira Spp.
Melosira sulcata

Navicula spp.
Navicula distans

Nitzschia spp.
Nitzschia delicatissima
Nitzschia longissima
Nitzschia seriata

Paralia sulcata

Pleurosigma nicobaricum

Rhizosolenia Spp.
Rhizosolenia alata
Rhizosolenia alata var. *curvirostris*
Rhizosolenia delicatula
Rhizosolenia fragilissima
Rhizosolenia setigera
Rhizosolenia stolterfothii

Skeletonema costatum

Stephanopyxis nipponica

(Contd.)

Table 2. (Contd.)

Streptotheca thamesis

Thalassionema nitzschoides

Thalassiosira spp.
Thalassiosira aestivalis
Thalassiosira angstii
Thalassiosira condensate
Thalassiosira decipiens
Thalassiosira eccentrica
Thalassiosira gravida
Thalassiosira leptopus
Thalassiosira lineata
Thalassiosira nordenskioldii
Thalassiosira pacifica
Thalassiosira polychorda
Thalassiosira rotula
Thalassiosira subtilis

Thalassiothrix frauenfeldii

Tropodoneis antarctica var. *polyplasta*

Miscellaneous Centric spp.

Miscellaneous Pennate spp.

B. Primary Productivity and Nutrients

The general features of the seasonal and spatial patterns of primary productivity measured in 1978 agree with 1976 observations (Larrance, et al. 1977). Typical cross-channel profiles of temperature, salinity, sigma-t, chlorophyll-a, and nutrients are illustrated in the Appendix. Winter conditions prevail in March: high nutrients, low chlorophyll and productivity and cold, well mixed water (Figs. 7 and 8; Appendix). In May, near-surface water in Kachemak Bay was thermally stratified and a large phytoplankton bloom was in progress. Daily productivity averaged about 7 g C/m^2 and nitrate and silicate were roughly half of the March values. At other stations nutrients were significantly lower, and productivity and chlorophyll were slightly higher than in March. Incident radiation had also increased (Table 3).

A large bloom was in progress in the western inlet (Kamishak Bay) in June where productivity averaged 4.6 g C/m2day, almost identical to the values measured in Kachemak Bay at that time. Productivity in mid-inlet was slightly higher than in May. Chlorophyll on the eastern side of the inlet had reached large values as a result of the sustained bloom and relatively low flushing rates of outer Kachemak Bay. Nutrients in the western inlet decreased dramatically between May and June, but remained moderately high in the central inlet where deeper, nutrient-rich, cold water rises to the surface.

The Kamishak Bay bloom had subsided to about% of its June value by July but the Kachemak Bay productivity remained high until August. It was not until August, that high productivity (averaged 5.3 g C/m^2day) was observed in the central inlet.

The major factors responsible for initiating blooms in lower Cook Inlet are water stratification, incident radiation, and water clarity. No blooms occurred unless the water column was thermally stratified, incident light averaged over 20 einsteins/m2day and the euphotic zone was deeper than about 10 m. These conditions occur first in Kachemak Bay where water resides in a gyre system relatively longer than in the central and western portions of the inlet. This longer residence time and lower mixing rates permits surface water to warm in the spring and retains phytoplankton populations where their concentrations can build to high levels. Because the major component of Kachemak Bay water originates in the Gulf of Alaska, it does not contain the heavy load of

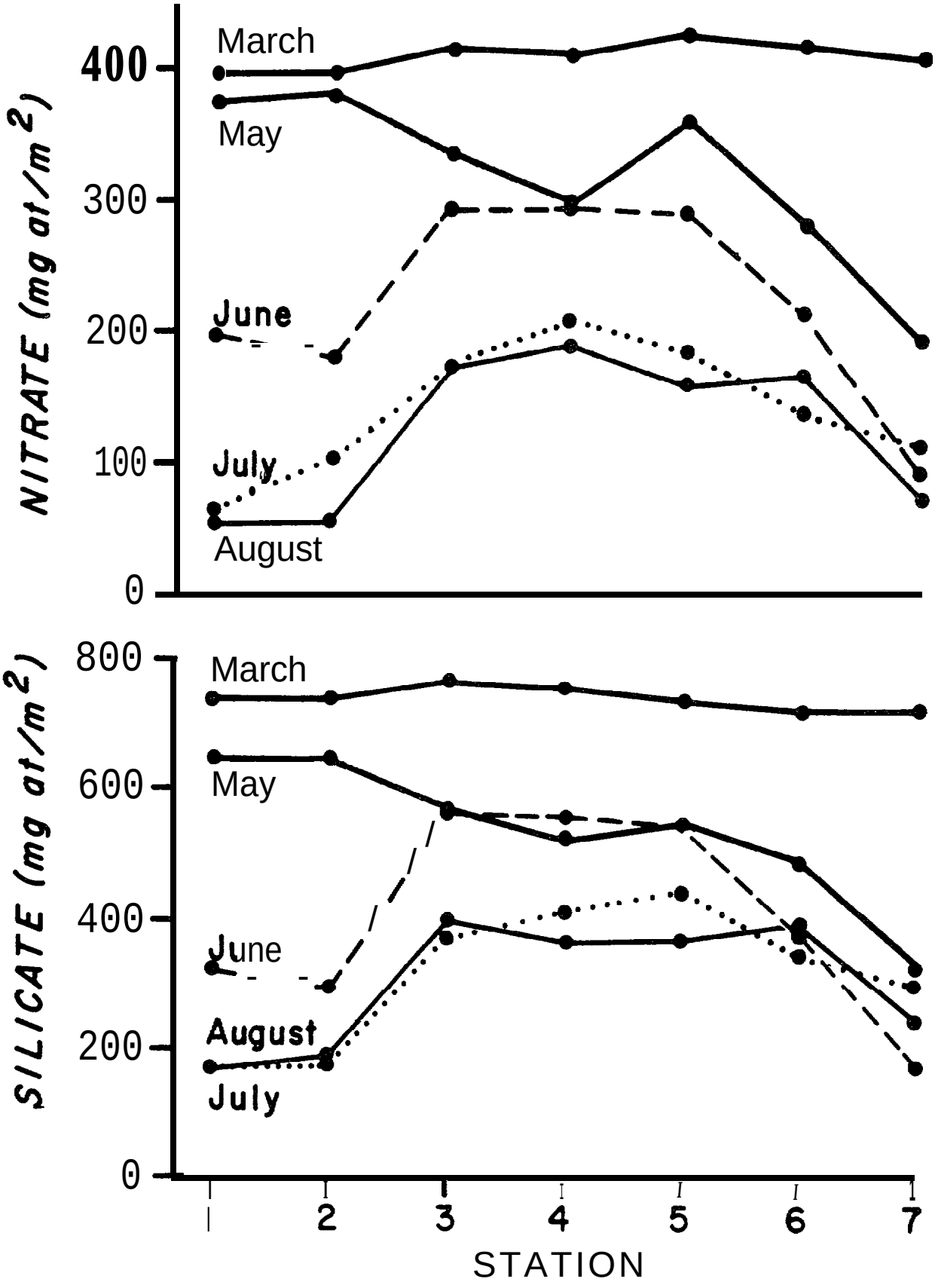


Figure 7. Nitrate and silicate in the upper 25 m, lower Cook Inlet, 1978.

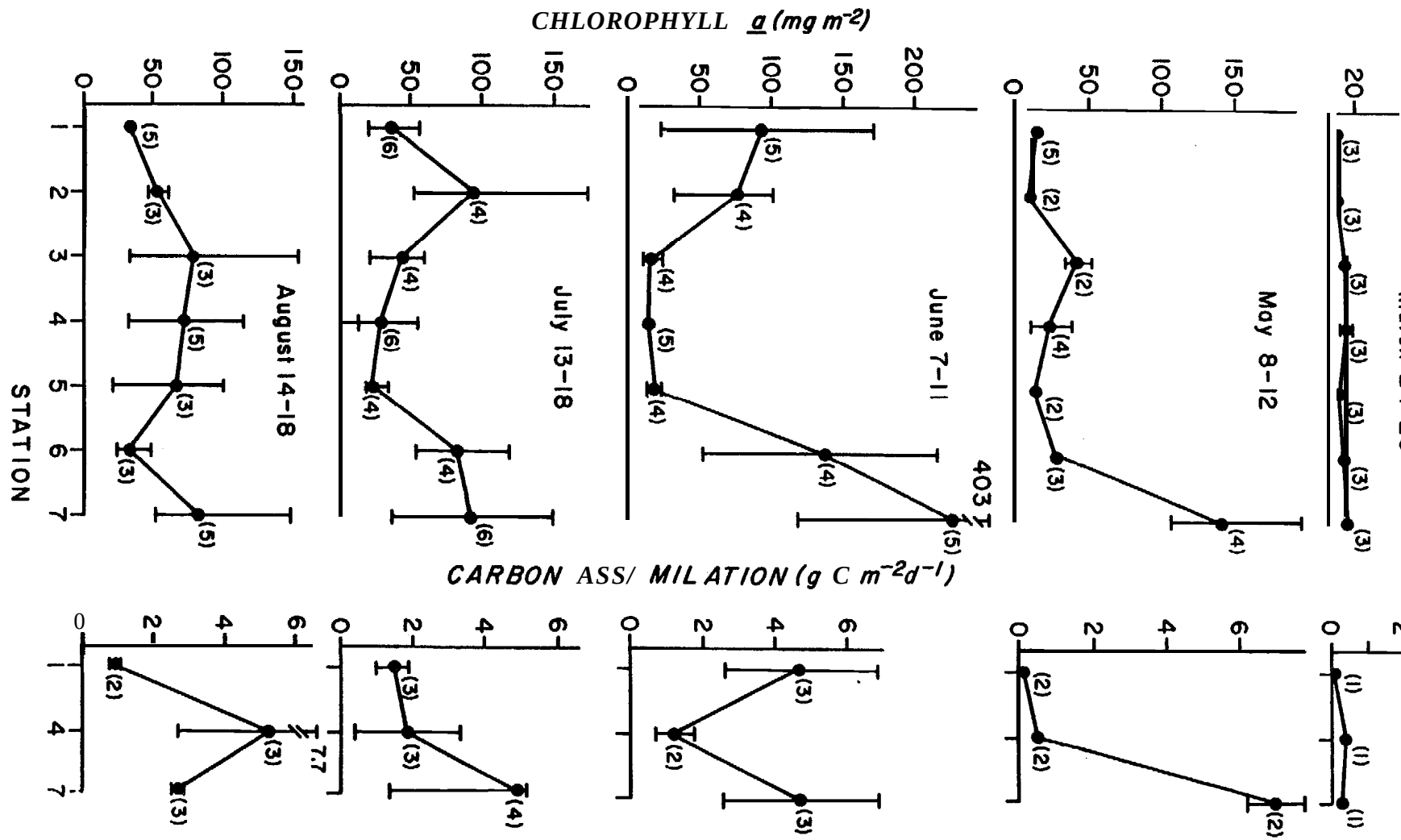


Figure 8. Chlorophyll in the upper 25 m and carbon assimilation in the euphotic zone of lower Cook Inlet, 1978. Bars indicate total range of observations; ( ) indicates number of profiles measured; plotted points are mean values.

Table 3. Chlorophyll, primary productivity, nutrients, and light.

Cruise/ Station	Local Date	Chlorophyll a (mg/m^2)	Primary Production ($\frac{mg\ C}{m^2\text{-}dy}$)	Nitrate ($\frac{mg\text{-}at}{m^2}$)	Silicate ($\frac{mg\text{-}at}{m^2}$)	Incident Radiation ($\frac{einsteins'}{m^2\text{-}dy}$)	1% Light Depth (m)
LCI781/1	24 MAR	6.5	31	395	734	*23.0*	5
2		7.0		397	737		5
3		11.6		413	763		19
4		11.3		411	758		19
5		8.7		427	736		24
6		11.5		419	720		
7		13.5		409	722		
7	25 MAR	12.7	283	403	724	*15.4*	24
6		12.5					24
5		9.3					27
4		9.5					27
3		10.5					22
2		7.4					
1		7.7					
1	26 MAR	7.3				*13.7*	
2		5.4					4
3		13.2					11
4		17.2	391				24
5		8.4					27
6		9.9					27
7		13.0					23

Table 3. (Contd.)

Cruise/ Station	Local Date	Chlorophyll a (mg/m^2)	Primary Production ($\frac{mg\ C}{m^2\text{-}dy}$)	Nitrate ($\frac{mg\text{-}at}{m^2}$)	Silicate ($\frac{mg\text{-}at}{m^2}$)	Incident Radiation ($\frac{einsteins}{m^2\text{-}dy}$)	1% Light Depth (m)
LCI782/1	8 MAY	13.9					2
1	9 MAY	15.9	86	383	642	18.9	3
7		104.7	6255	175	357		15
6		28.6					24
4		33.7					19
7	10 MAY	136.4		177	326	17.2	
4		39.0		315	541		23
1		12.6		366	642		6
7	11 MAY	197.2	7815	293	281	28.5	15(1)
6		32.9		292	496		
5		16.8		361	620		30
4		10.9	557	308	538		32
3		50.8		337	588		19
2		11.4		379	648		5
1		13.5		384	682		5
1	12 MAY	19.7	204	368	616	28.0	5(1)
2		9.0		381	639		7
3		34.5		340	557		24
4		11.9	473	277	489		27
5		11.1		361	581		35
6		26.4		275	480		24
7		122.4		137	292		16

Table 3. (Contd.)

Cruise/ Station	Local Date	chlorophyll a (mg/m^2)	Primary Production mg C / m^2-dy	Nitrate (mg-at / m^2)	Silicate (mg-at / m^2)	Incident Radiation, einsteins / m^2-dy	1% Light Depth (m)
LCI783/7	7 JUN	116.8		116	222	52.9	8
1		22.9		229	390		11
4		15.6		297	530		20
1	8 JUN	39.2	2598	255	454	34.2	11(1)
2		31.7		274	477		
3		16.1		298	573		22
4		13.0	641	289	570		22
5		13.6		298	561		31
6		51.4		230	398		20
7		156.9		89	168		13
1	9 JUN	79.5	4406	167	282	26.0	11(1)
2		100.6		139	203		
3		15.2		291	566		24
4		15.5		296	565		27
5		22.4		283	518		27
6		148.5		204	336		19
7		295.9	6877	102	185		11
7	10 JUN	402.7	4585	75	147	50.6	11(1)
6		130.5		206	393		
5		17.3		290	558		35
4		13.4	1759	300	573		35
3		10.5		297	548		29

Table 3. (Contd.)

Cruise/ Station	Local Date	Chlorophyll a (mg/m^2)	Primary Production mg C [m^2-dy]	Nitrate mg-at [m^2]	Silicate mg-at [m^2]	Incident Radiation einsteins [m^2-dy	1% Light Depth (m)
2		75.8		129	196		13
1		170.7		168	261		11
1	11 JUN	157.5	6849	145	219	49.4	11(1)
2		97.0					
3		19.0					35
4		13.0					40
5		22.4					50
6		215.8					19
7		161.6	2560	80	136		14
LCI784/1	13 JUL	34.3				21.1	
4		13.7					30
7		71.5					12
7	14 JUL	147.8	5089	77	181	47.3	12(1)
6		118.6		127	276		11
5		18.7		192	442		33
4		41.5	3298	197	394		20
3		21.4		204	396		19
2		51.6		147	250		15
1		25.2		61	153		10
1	15 JUL	33.2	1845	46	143	25.4	10(1)
2		65.2					11
3		43.6					14
4		16.3	778	223	451		17

Table 3. (Contd.)

Cruise/ Station	Local Date	chlorophyll a (mg/m^2)	Primary reduction $\frac{mg\ C}{[m^2\text{-}dy]}$	Nitrate $\frac{mg\text{-}at}{[m^2]}$	Silicate $\frac{mg\text{-}at}{[m^2]}$	Incident Radiation einsteins m^2- dy	1% Light Depth (m)
5		19.4					27
6		72.0					15
7		141.3					12
7	16 JUL	40.8	3441	90	259	43.1	12(1)
6		90.6		135	368		
5		34.7		192	465		16
4		28.9	1381	225	388		14
3		54.2		141	358		14
2		172.2		65	124		16
1		21.8		90	202		11
1	17 JUL	42.7	958	78	207	10.8	11(1)
4		55.2					
7		107.0	4654	120	348		15
7	18 JUL	36.6	1320	165	417	10.1	15(1)
6		53.4		151	381		
5		20.3		174	423		
4		19.8		196	434		16
3		59.6		189	357		15
2		88.3		96	159		15
1		55.3	1601	38	151		15
LCI785/1	14 AUG	34.3		29	133		
4		70.5		79	292		15

Table 3. (Contd.)

Cruise/ Station	Loca Date	Chlorophyll (mg/m^2)	Primary Productio $\left(\frac{mg\ C}{m^2\text{-}dy}\right)$	Nitrate $\left(\frac{mg\text{-}at}{m^2}\right)$	Silicate $\left(\frac{mg\text{-}at}{m^2}\right)$	Incident Radiatio einstein: m^2 - dy	1% Ligh Depth (m)
7		71.7		90	283		21
7	15 Au	71.9	2840	37	174	46.1	21(1)
6		48.3		177	398		24
5		100.2		151	377		18
4		68.0	5388	180	393		30
3		50.0		186	420		19
2		45.9		37	13.1		
1		30.2		38	157		18
1	16 AU(	36.6	785	63	180	12.2	18(1)
4		115.2		192	378		14
7		72.5	2726	105	284		24
7	17 AU(	52.4	2516	115	326	51.6	24(1)
6		28.7		152	385		19
5		78.8		159	342		22
4		75.5	7690	148	372		18
3		153.8		146	380		
2		60.2		66	193		12
1		31.9		69	187		12
1	18 AUG	35.5	1075	68	201	44.2	12(1)
2		49.7		59	243		
3		34.6		188	400		14
4		33.4	2689	170	385		17

Table 3. (Contd.)

Cruise/ Station	Local Date	Chlorophyll a (mg/m^2)	Primary Production ($\frac{mg\ C}{m^2\text{-}dy}$)	Nitrate ($\frac{mg\text{-}at}{m^2}$)	Silicate ($\frac{mg\text{-}at}{m^2}$)	Incident Radiation ($\frac{einsteins}{m^2\text{-}dy}$)	1% Light Depth (m)
5		21.5		172	391		30
6		25.0		174	408		24
7		146.4		22 .	141		

(1) For morning incubations the 1% 1 ight depth was chosen based on the previous day's value.

suspended particles present in the upper Cook Inlet water which sweeps the western side. Kachemak Bay, therefore, is relatively clear prior to the spring bloom. The western inlet, however, remained highly turbid with silt and other non-living particles until June when it cleared sufficiently to permit a phytoplankton bloom. The central inlet is an upwelling area (Muench, et al., 1978) which does not easily stratify.

Nutrients (primarily nitrate, ammonium and silicate) do not appear to decrease to limiting levels except in Kachemak Bay, and perhaps, to a lesser extent, in Kamishak Bay. High rates of grazing by fecal-pellet-producing zooplankton are evident by the content of sediment trap samples. It is likely, therefore, that considerable nutrient regeneration by zooplankton occurs and helps to support the observed production of algae, even though observed nutrient concentrations remain low. Nutrients are also supplied by mixing with Gulf of Alaska water entering Cook Inlet. Nutrient concentrations in the central inlet decrease to moderate levels by July, butnotto the extent which would significantly limit production.

C. Sediment Trap Studies

Sediment trap samples were analyzed for total particulate matter, plant pigments, organic carbon, nitrogen, and numbers of fecal pellets, phytoplankton cells, and other identifiable particles. Adequate samples resulted from 15 of the 24 sediment traps deployed. Because of the use of replicate traps, useable samples were obtained from 10 of the 12 moorings set out in Cook Inlet. Replicate trap samples were obtained at 5 stations. Variability was large, but in line with that found in other studies (Spencer et al. 1978). The coefficient of variation for total particulate flux averaged 36% in the central inlet and and 16% in Kachemak and Kamishak Bays. See Table 4 for five sets of paired values. Dry weights for the total samples ranged from about 0.2 to 6 g and provided sufficient material for the required chemical and microscopical analyses.

Total Particulate Flux--Total particulate flux measurements help clarify the different cross-channel sedimentary environments. Comparisons with sedimentation rates independently estimated from Pb-210 data (Richard A. Feely, RU #152, personal comm.) provide a field calibration technique for verifying sediment trap efficacy. Long-term sedimentation rates measured by Feely from May-August 1978 at a mooring situated near our station 1 provide added confir-

mation that our short-term deployments measured representative particulate flux.

Rates of sedimentation for each cruise and station are summarized in Table 4. Particulate flux in Kachemak Bay was remarkably uniform and reflected the high biological productivity present there throughout the study. Observed settling rates were more variable in Kamishak Bay. The extremely high May value (72 g/m^2-day) was correlated with heavy suspended loads carried down from the upper inlet at that time of year.

Time-averaged sedimentation rates during the May-August period were calculated and compared with long-term accumulation rates found from cores analyzed for Pb-210 activity (Table 5). Given the uncertainties involved, there is good agreement between estimates by the two methods. Kachemak Bay is characterized by high phytoplankton concentrations during late spring and summer, with less sedimentation likely during the winter. The measured flux during the biologically productive period, therefore, can be expected to be higher than the long-term estimates derived from Pb-210 geochronology. In contrast, during the early spring, Kamishak Bay water has high concentrations of glacially derived suspended matter transported from the upper inlet. Summertime inputs due to local organic production are relatively low. Sediment traps were in place during both sedimentary periods, and the two methods of estimate are in closer agreement. It is therefore likely that the sediment traps are measuring typical particle flux and that these particles accumulate in the sediments of Kachemak and Kamishak Bays.

Sediment traps were deployed by R. A. Feely (RU#152) for an 85-day sampling period at a station (his ST-1) approximately 10 miles west of our Kamishak Bay site. This long-term flux was estimated to be about 21 g/m^2-day, and it compares reasonably well with our time-averaged value for Kamishak Bay. The $21g/m^2$ -day figure is a long-term (85 days) sediment trap measurement by Feely and should not be confused with the Pb-210 estimate ($27g/m^2$-day) listed in Table 5. These data provide complimentary evidence that short-term deployments measured typical flux in the region.

Microscopic Investigations--Microscopic examination and enumeration of particulate components in sediment trap samples provide information about the quality and quantity of organic particles sinking to the sea floor (Table 6). By far, the major portion of material was in the form of recognizable fecal

Table 4. Total sedimentation rate at lower Cook Inlet stations, May-August 1978. Paired values are from replicate sediment traps.

Location	Time	Total Particulate Flux (g/m^2-day)	
Kamishak Bay (Sta. 1)	May	72.0	
	June		
	July	6.4	
	August	13.2	17.1
Central Inlet (Sta. 4)	May	11.3	7.5
	June	17.6	26.6
	July	1.9	
	August	13.2	6.1
Kachemak Bay (Sta. 7)	May	17.3	
	June	22.1	
	July	-	
	August	19.5	16.5

Table 5. Average sedimentation rates in lower Cook Inlet estimated from sediment trap data (May-August 1978) and long-term Pb-210 radiometry.

Location	Station No.	Average Sedimentation (Sediment Traps) g/m^2-day	Average Accumulation (^{Pb}-210 Radiometry) g/m^2-day
Kamishak Bay	1	30.7	27.1
Central Inlet	4	11.1	no data
Kachemak Bay	7	20.0	10.5

Table 6. Daily particulate flux (numbers/m^2) settling near bottom in lower Cook Inlet, 1978.

		FECAL PELLETS x10^6	DIATOMS x10^6	TINTINNIDS x10^6	DINOFLAGELLATES x10^6	MOLTS x10^6	LARvAE: Copepods	Barnacles	Clams	Polychaetes	Crabs	Snails	Octopus
Kachemak	May	0.360	13.41	0.114	0.023	0.027	X		X				
	Jun	0.932	15.82	0.408	0.024	0.016	X	X	X	X	X		
	Jul	-----	-----	-----	-----	-----	-	-	-	-	-	-	-
	Aug	3.110	9.40	2.355	0.240	0.046	X	X	X		X	X	
Central	May	0.247	154.07	0.148	0.018	0.001				X			
	Jun	2.010	14.23	0.489	0.073	0.006	X	X			X		
	Jul	0.079	7.27	0.041	0.010	0.001	X		X				
	Aug	0.119	196.22	0.118	0.012	0.004	X		X			X	
Kamishak	May	0.092	20.05	0.199	0.133	0.000	X						
	Jun	-----	-----	-----	-----	-----	-	-	-	-	-	-	-
	Jul	0.750	9.29	0.367	0.208	0.016	X		X	X		X	
	Aug	1.830	6.75	1.158	0.025	0.034	X	X	X			X	X

pellets. Scanning electron micrographs of these products of zooplankton grazing activity reveals many broken remains of diatom frustules (Fig. 9). The flux of intact fecal pellets averaged for all cruises and stations was about one million pellets/m^2 day. The maximum flux (3.11 x $10^6/m^2$ day) was measured in Kachemak Bay during August. The dimensions of individual pellets averaged about 200 um long by 50 um wide. As a rule, the largest pellets were found in Kachemak Bay. Shuman (1978) reported mean sinking rates for similarly sized fecal pellets to be about 150 m/day. At this speed it would take only one-half day for a fecal pellet to sink from the surface to the bottom of even our deepest station. Our sediment traps are, therefore, likely measuring fecal input which is closely coupled in time to the actual grazing events. In addition to intact fecal pellets, there were often quantities of amorphous debris which appeared to come from broken pellets. This unidentifiable debris could easily be "manufactured" under the dissecting scope by physically breaking whole fecal pellets with a probe.

Honjo and Roman (197%) observed rapid bacterial colonization of the surface membrane of fecal pellets exposed to seawater. The rate of membrane rupture increased from 3 hours at 20°C to 20 day at 5°C. Thus, in Cook Inlet, rapid transport to the bottom and relatively cold temperatures insure the arrival of fresh fecal material to the benthos. Copepod fecal pellets have been shown to reflect the chemical composition of ingested food and represent a rich energy source for detritus (Cowey and Corner 1966). Johannes and Satomi (1966) studied the nutritive value of fecal pellets produced by an omnivorous marine crustacean fed on diatoms and concluded that the feces were rich in assimilable protein. The authors suggested that food residues are converted into assimilable bacteria in the posterior portion of the crustacean gut, and that fecal pellets represent a major potential food source for marine animals.

Besides fecal pellets and debris, other large particles included crustacean molt material and, also, a variety of juvenile invertebrates (Table 6). Fluxes of molt material ranged from 0 to 4.6 x $10^5/m^2$day, and were most common in Kachemak and Kamishak Bays during August. This corresponded with the period

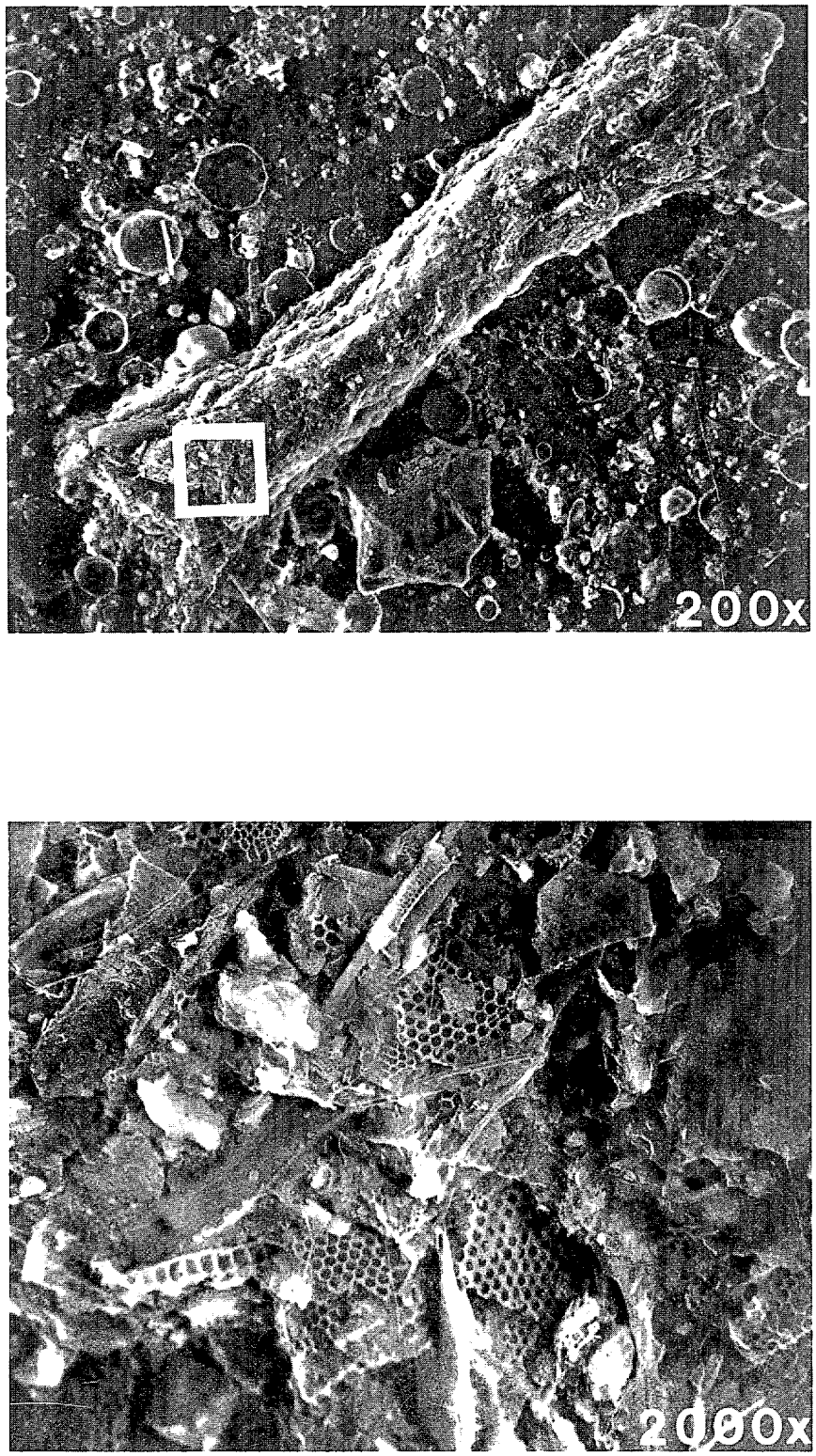


Figure 9. Scanning electron micrographs of fecal pellets. Whole fecal pellet (lower, 2000x); diatom fragments in lower inset (upper, 20,000x).

of greatest fecal pellet flux for these two regions of Cook Inlet.

Occasionally, larvae of barnacles, clams, polychaete worms, snails, and other bottom settling invertebrate juveniles were found in the traps. These larvae begin life as members of the plankton and, after development, settle downward to take up a benthic existence. The presence of these organisms in the traps hints at a potential method for measuring settling and recruitment rates of invertebrates to specific subtidal habitats. For example, about 16,000 lamellibranch (clam) larvae/m^2day were deposited at Kamishak Bay in July; almost 6000 barnacle cyprids/m2day were deposited there in August. This kind of data would be useful to specialists in benthic population dynamics,

Smaller particles in the traps were enumerated with an inverted microscope. These included primarily phytoplankton cells and tintinnid protozoans. Diatom cells and resting spores were by far the most abundant phytoplankters in the traps. The input rates of diatoms were on the order of 10-20 x 10^6 cells/m^2day, except for May and August, when large fluxes of small pennate diatoms predominated in the center of the inlet. Relatively few dinoflagellates and no microflagellates were observed in the samples, probably due to the ability of these cells to swim against gravity. Contrary to Shuman's (1978) observation that dominant phytoplankton species were not significantly found in sediment traps, our data strongly demonstrate a flux of the important diatom species to the bottom. This apparent discrepancy may be due to the greater water depth and correspondingly longer sinking times in Shuman's area of study.

The occurrence of large numbers of tintinnid loricae in the traps is significant and may give some indication of the natural mortality experienced by this group of active phytoplankton grazers. Tintinnids are ciliated protozoans, each housed in a pseudo-chitonous organic sheath called a lorica. Many coastal and neritic tintinnids, including important genera found in the sediment traps, decorate their loricae with mineral particles scavenged from the water column (Gold and Morales 1976). This provides another potential biological mechanism for concentrating oiled particles and transferring them to the sea floor.

Pigment Studies--A major goal of the present study has been to quantify the loss rate of phytoplankton material to the sea floor in terms of the algal

biomass in the overlying water. As outlined in the introductory conceptual model, the purpose has also been to provide an assessment of the relative importance of the grazing and sinking loss functions. The chlorophyll a molecule is particularly well-suited for use in this inquiry because it supplies some index of overall plant biomass. Most significantly, chlorophyll a and its degradation products can also function as tracer molecules to study the fate of phytoplankton material in the marine environment. Since chlorophyll is completely degraded to pheophorbide in the herbivore gut (Shuman and Lorenzen 1975), the amount of chlorophyll eaten can be directly calculated from the pheophorbide content. Because our calculations are done on a weight rather than a molar basis, the total conversion of chlorophyll to pheophorbide would involve a 34% weight-loss correction from the original weight of chlorophyll. This 34% decrease represents the molecular weight loss of the central Mg atom and the phytol chain from the chlorophyll molecule. The total loss of chlorophyll from the water column to the traps is calculated as

$$\text{Total Chlorophyll Lost from water column} = \text{Chlorophyll in trap (sinking)} + \frac{\text{Pheophorbide in trap}}{.66 \text{ (grazing)}}$$

where the corrected pheophorbide value represents the grazed chlorophyll lost. We have ignored any possible small disappearance of chlorophyll degradation products in the dark.

By measuring the chlorophyll and chlorophyll degradation products in the sediment traps, it is therefore possible to arrive at not only the total phytoplankton biomass lost to the bottom, but also to assess the relative contribution of grazing and sinking to that loss. The grazing losses estimated here are almost exclusively due to grazing pressure exerted by fecal-pellet-producing zooplankton. Grazing by tintinnids and other microzooplankton species which void their waste products in an unconsolidated form is not adequately accounted for because the traps do not effectively sample those products.

The total algal biomass lost from the water column is reported as equivalent chlorophyll flux which is the sum of chlorophyll and adjusted pheophorbide (Table 7). The greatest absolute chlorophyll losses were always measured in Kachemak Bay which is consistent with the characterization of that area as one of extremely rich organic production. On the average, plant-pigment fluxes were almost six times greater for Kachemak Bay than for the other two Cook

Table 7. Phytoplankton standing stock and grazing losses calculated from pigment analyses of particles collected in sediment traps, lower Cook Inlet, 1978.

Location	Month	Total Particulate Matter (TPM) g m^{-2} day^{-1}	Chlorophyll Equivalents mg m^{-2} day^{-1}	Standing Stock Lost, %	Grazing Loss %	TPM / Chl-*a* Equivalents mg mg^{-1}
KAMISHAK BAY (Sta. 1)	May	72.0	1.6	9.9	90	45,570
	Jun					
	Jul	6.4	3.0	7.2	61	2,126
	Aug	15.2	3.1	9.2	81	4,844
CENTRAL INLET (Sta. 4)	May	9.4	1.9	4.1	89	4,836
	Jun	22.1	5.0	18.2	85	4,545
	Jul	1.9	1.0	2.6	88	1,845
	Aug	9.6	1.5	1.6	87	6,375
KACHEMAK BAY (Sta. 7)	May	17.3	17.2	8.5	79	1,005
	Jun	22.1	14.4	5.7	81	1,529
	Jul					
	Aug	18.0	11.3	7.6	89	1,590

Inlet sites. Also, the ratio of total particulate flux to pigment flux indicates the higher relative organic richness of the Kachemak Bay sediments.

The total equivalent chlorophyll flux was compared to the time-averaged chlorophyll content of the overlying waters during the period of sediment trap deployment to obtain an estimate of the portion of the phytoplankton population lost each day by sinking or grazing (Table 7). At Kachemak and Kamishak Bays, the daily loss to the phytoplankton standing stock amounted to about 8% (s.d. = 1.5%). Loss rate values for the central inlet were much more variable but averaged about 6.5% (s.d. = 7.5%). Of this total plant material lost to the bottom, an average of 83% (s.d. = 8.6%) was attributed to grazing and subsequent fecal pellet production. The balance resulted from either direct algal sinking or possibly the presence of a few undigested chlorophyll bearing cells in the fecal pellets.

These values for the proportion of the phytoplankton population sedimented to the sea floor per-day, as well as the relative dominance of grazing, agree quite well with Shuman's (1978) conclusions for a small Puget Sound embayment. The conclusions of both studies are consistent with the argument that grazing, and not direct sinking of algal cells, represents the major loss from the phytoplankton population.

The relationship between estimated chlorophyll grazed and fecal pellets found in the traps was explored to test whether increased grazing indexed by pheophorbide content could be linked with more direct evidence of zooplankton grazing. Positive statistical correlation was found between chlorophyll grazed and fecal pellet volume (Fig. 10). Although errors in fecal pellet flux measurements were introduced because of pellets broken during the collection and preservation process, the relationship is considered good corollary evidence that high grazing pressures are reflected in high pheophorbide concentrations in the traps. Pigment content of fecal pellets at station 7 was relatively high which indicates that fecal pellets produced in Kachemak Bay may be richer in phytoplankton remains than those at station 1 and 4. This view is consistent with data showing higher total particulate:pigment ratios in the sediment traps at stations 1 and 4 and suggests that zooplankton grazers may be ingesting relatively more inorganic (non-chlorophyll bearing) particles there than at station 7.

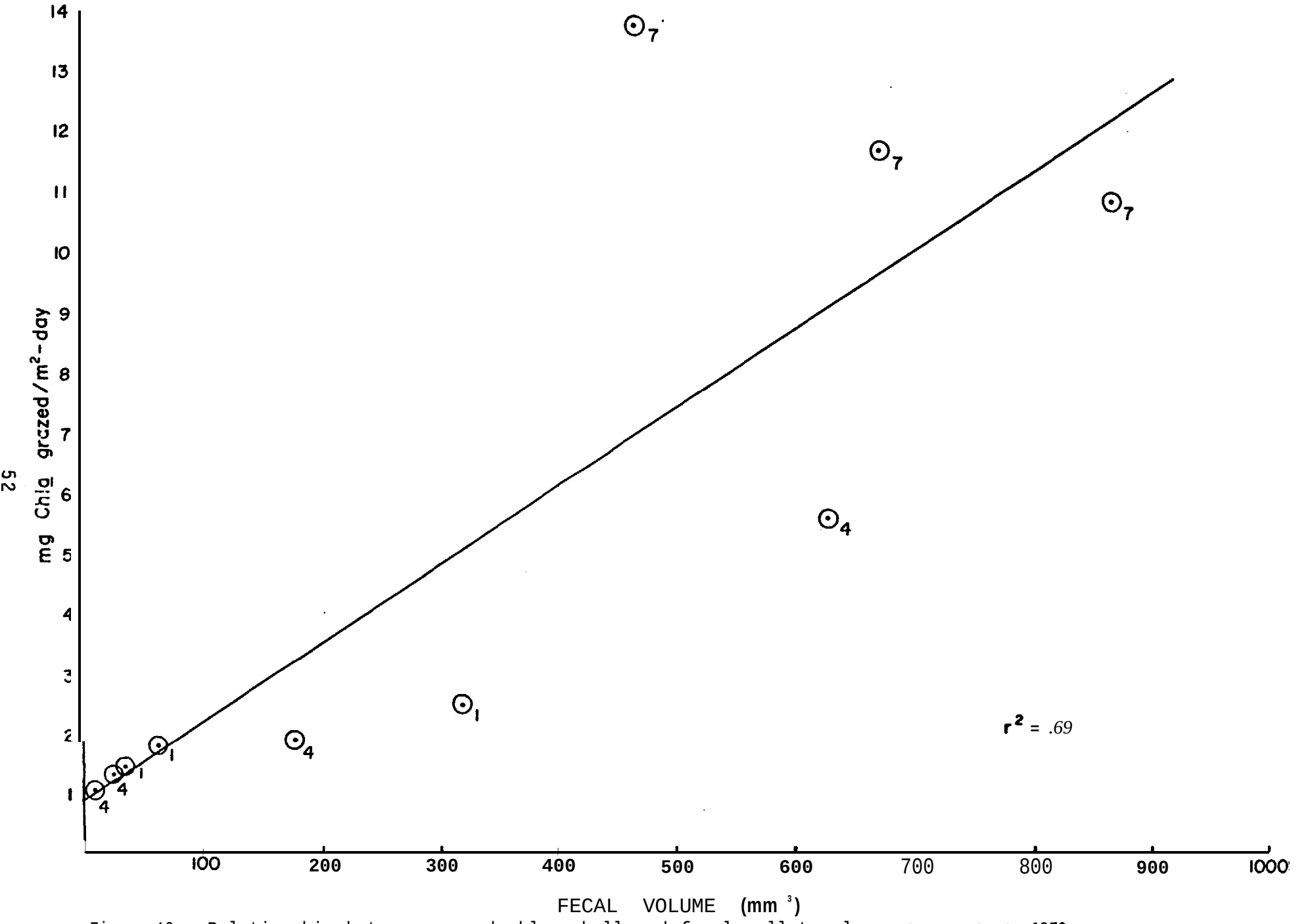


Figure 10. Relationship between grazed chlorophyll and fecal pellet volume, lower Cook Inlet, 1978.

A consideration of some important chemical ratios in the water column and in the sediment traps yields some insights into changes in the nature of organic matter as it is transferred to the benthos. Commonly, lower carbon:chlorophyll values were encountered in the sediment traps than in the overlying waters. The porphyrin ring of the chlorophyll is particularly stable, and other organic compounds are more easily assimilated by grazers. This stability supports the use of chlorophyll degradation products as tracer molecules in the marine environment.

A second important index is the carbon:nitrogen ratio. In every case, the C:N value was higher in the sediment traps than in the overlying water column. As plant material is metabolized during the digestive process, nitrogen-rich organic compounds are preferentially used, and C:N ratios increase. Knauer et al. (1979) reached a similar conclusion from sediment trap studies conducted in the Northeast Pacific Ocean.

VI. SUMMARY

The use of sediment traps has enabled us to determine the input rates of a variety of chemically and microscopically defined particles to the benthic food web of lower Cook Inlet. Areal and seasonal variations in flux and quality of material were determined and related to algal biomass and productivity in the overlying waters. Comparisons of particulate flux measured by sediment traps with long-term accumulation rates estimated by Pb-210 geochronology were quite favorable and lend confidence to the validity of the experimental approach.

Of the three sites studied, the greatest amount of organic material in trap samples was in Kachemak Bay. This is verified by chemical measures (i.e. pigment, carbon, and nitrogen fluxes), as well as by visual observations (i.e. fecal pellet and phytoplankton cell numbers). The sedimented material in Kachemak Bay was richer than in other areas of Cook Inlet in both organic carbon and nitrogen. Somewhat lower organic inputs occurred at Kamishak Bay, and the mid-channel region received even smaller quantities. These conclusions are in accord with the general distribution of primary productivity discerned by this and other studies, and they are also consistent with the overall patterns of benthic productivity in lower Cook Inlet.

Table 8. Particulate carbon and nitrogen in sediment trap samples, lower Cook Inlet, 1978.

Location	Month	Carbon wt.-%	Carbon Flux mg m^{-2} day^{-1}	Nitrogen wt.-%	Nitrogen Flux mg m^{-2} day^{-1}	Carbon / Chlorophyll Ratio	Carbon / Nitrogen Ratio
KAMISHAK BAY (Sta. 1)	May	0.85	612	0.075	50.4	387	12.9
	Jun	1.52*		0.182*			8.1*
	Jul	2.11	135	0.281	18.0	45	7.5
	Aug	1.66	252	0.180	27.3	81	9.6
CENTRAL INLET (Sta. 4)	May	1.12	105	0.107	10.1	54	12.1
	Jun	1.69	373	0.183	40.2	74	9.2
	Jul	0.74	14	0.064	1.2	14	11.5
	Aug	0.78	76	0.066	6.4	51	12.8
KACHEMAK BAY (Sta. 7)	May	2.60	450	0.358	61.9	26	8.8
	Jun	2.68	592	0.299	66.1	41	9.0
	Jul	3.34*		0.426*			7.7*
	Aug	2.60	468	0.360	64.8	41	7.2

* values obtained from traps that did not close properly

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APPENDIX:

Cross channel distributions of physical and chemical variables in lower Cook **Inlet, 1978.**

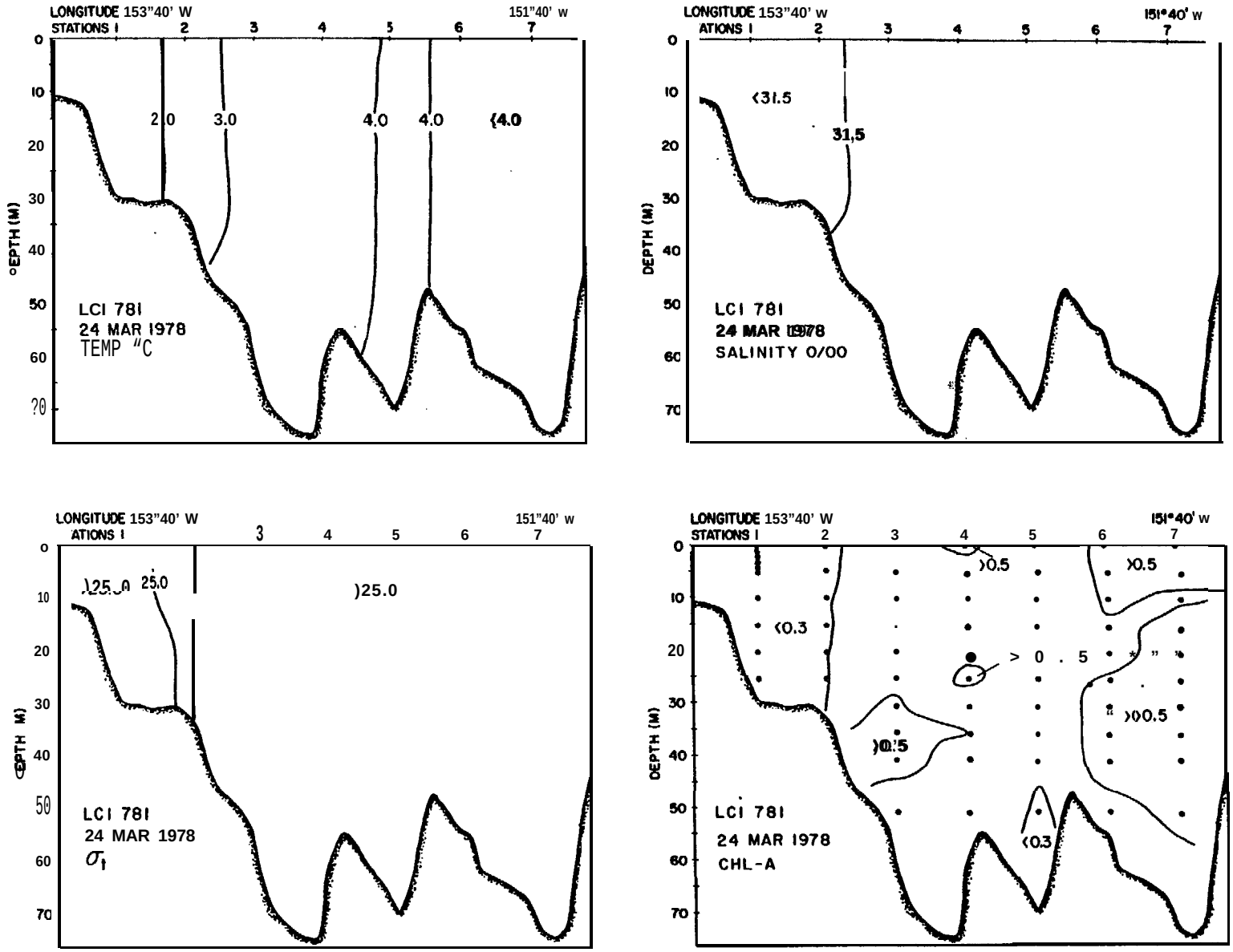

Figure A-1. Temperature, salinity, sigma-t, and chlorophyll-a, 24 March.

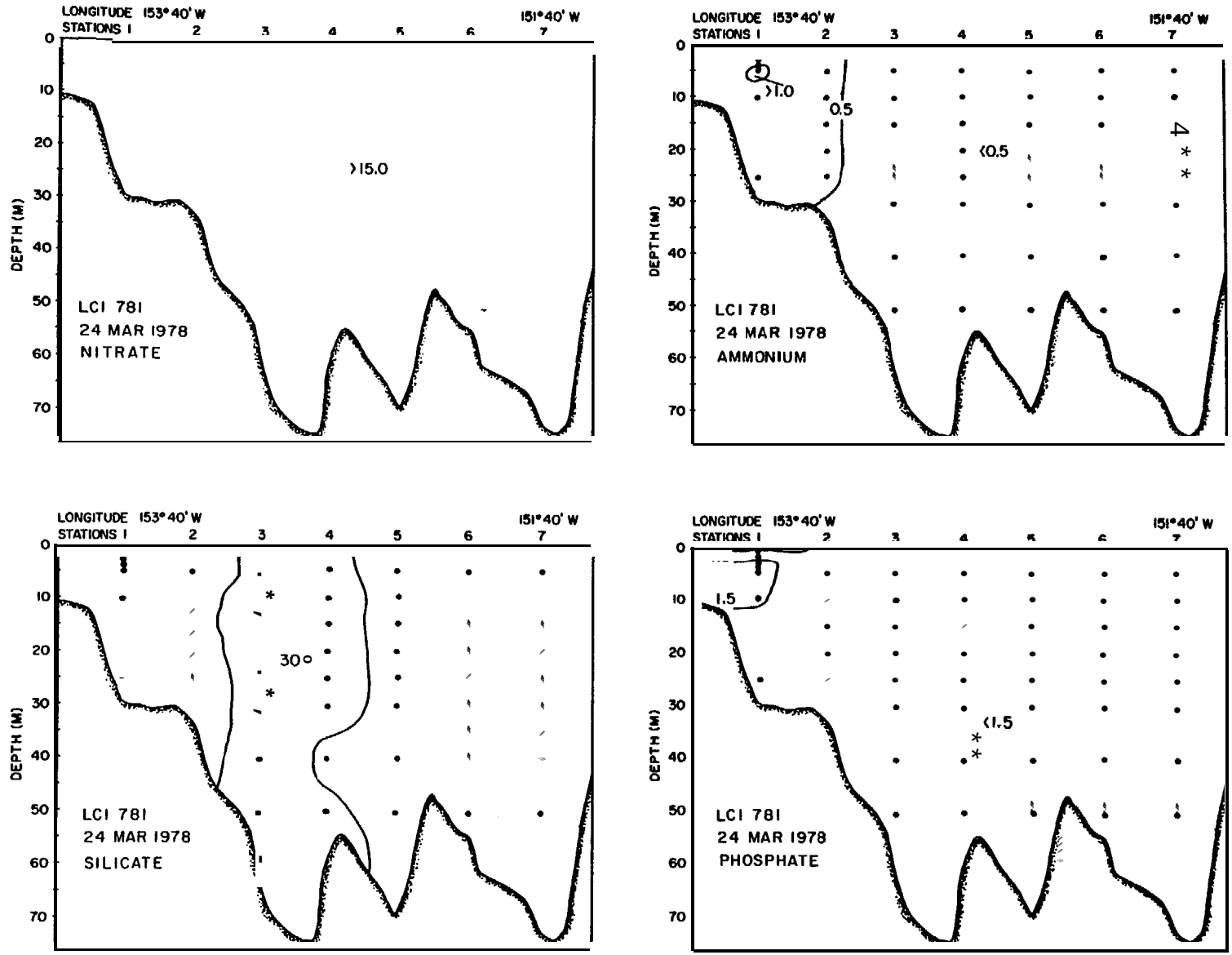

Figure A-2. Nutrients, 24 March

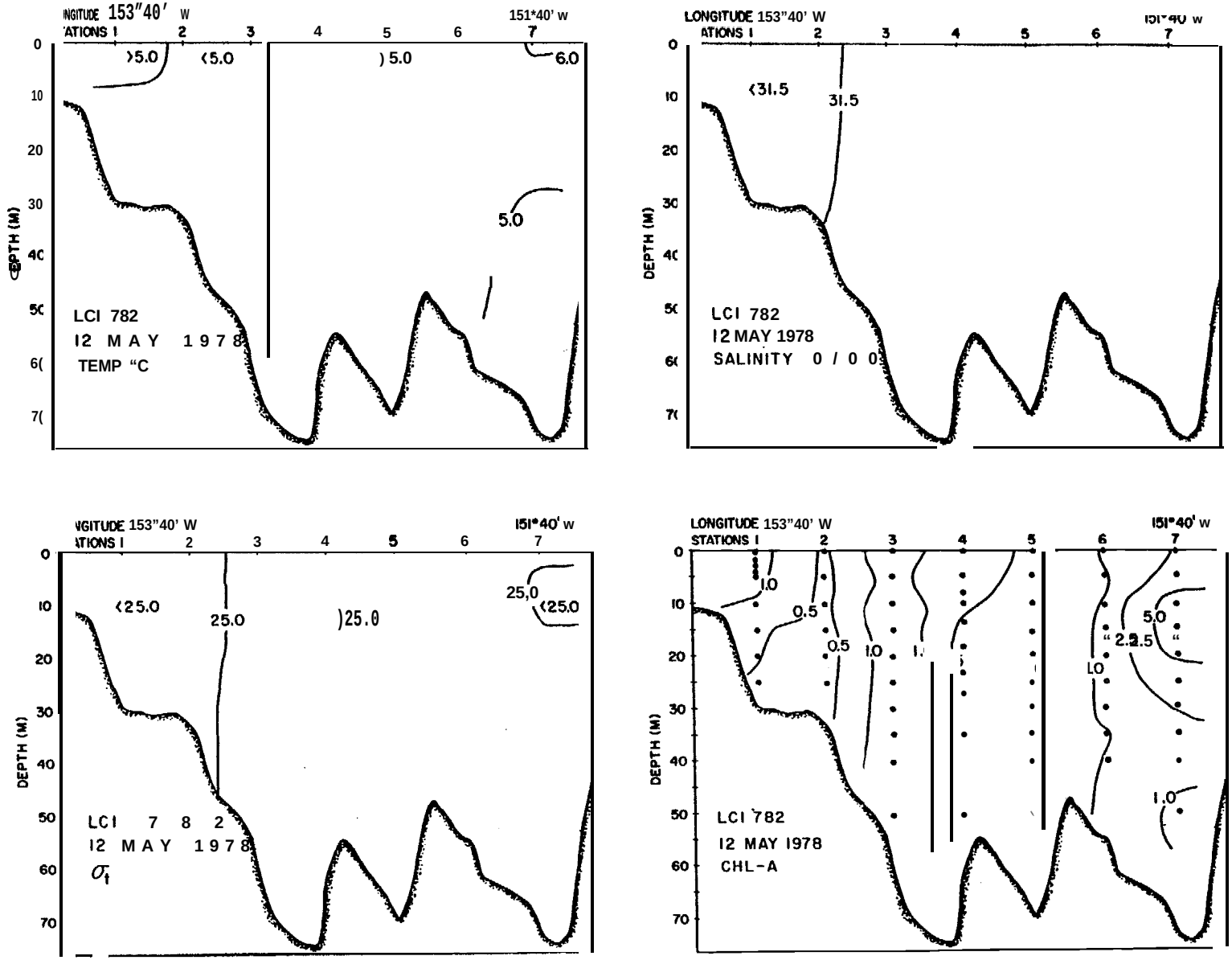

Figure A-3. Temperature, salinity, sigma-t, and chlorophyll-a_, 12 May.

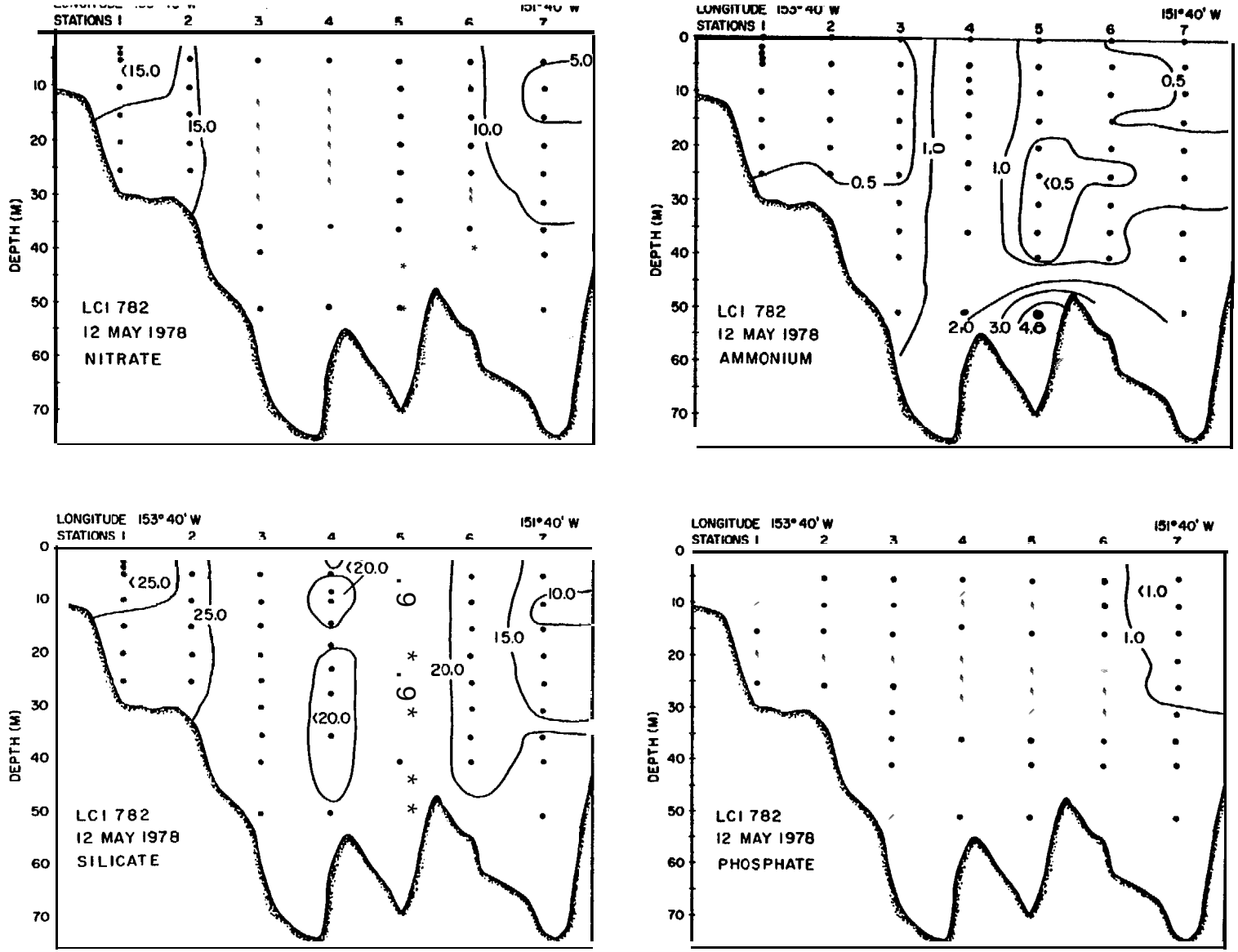

Figure A-4. Nutrients, 12 May.

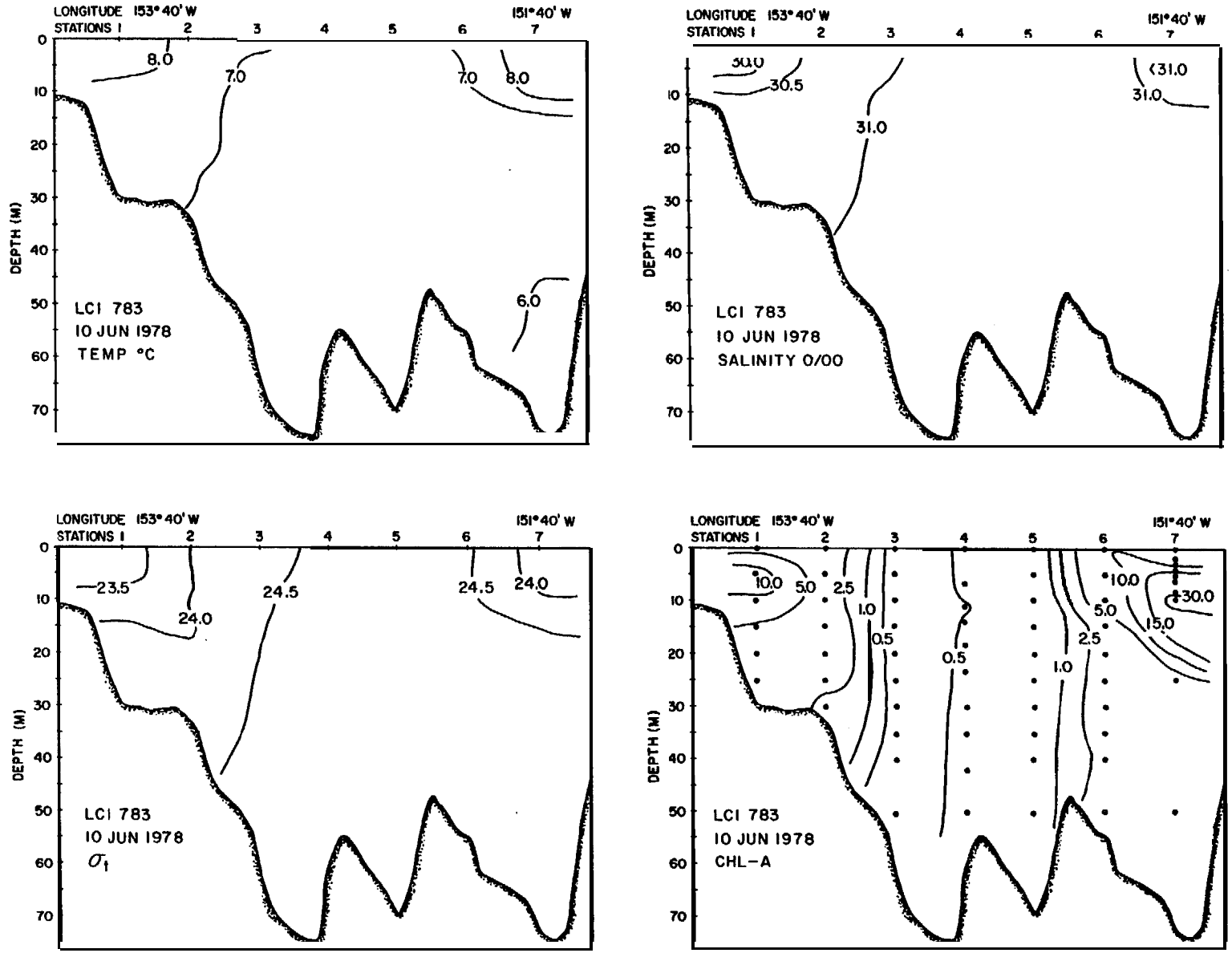

Figure A-5. Temperature, salinity, sigma-t, and chlorophyll-a, 10 June.

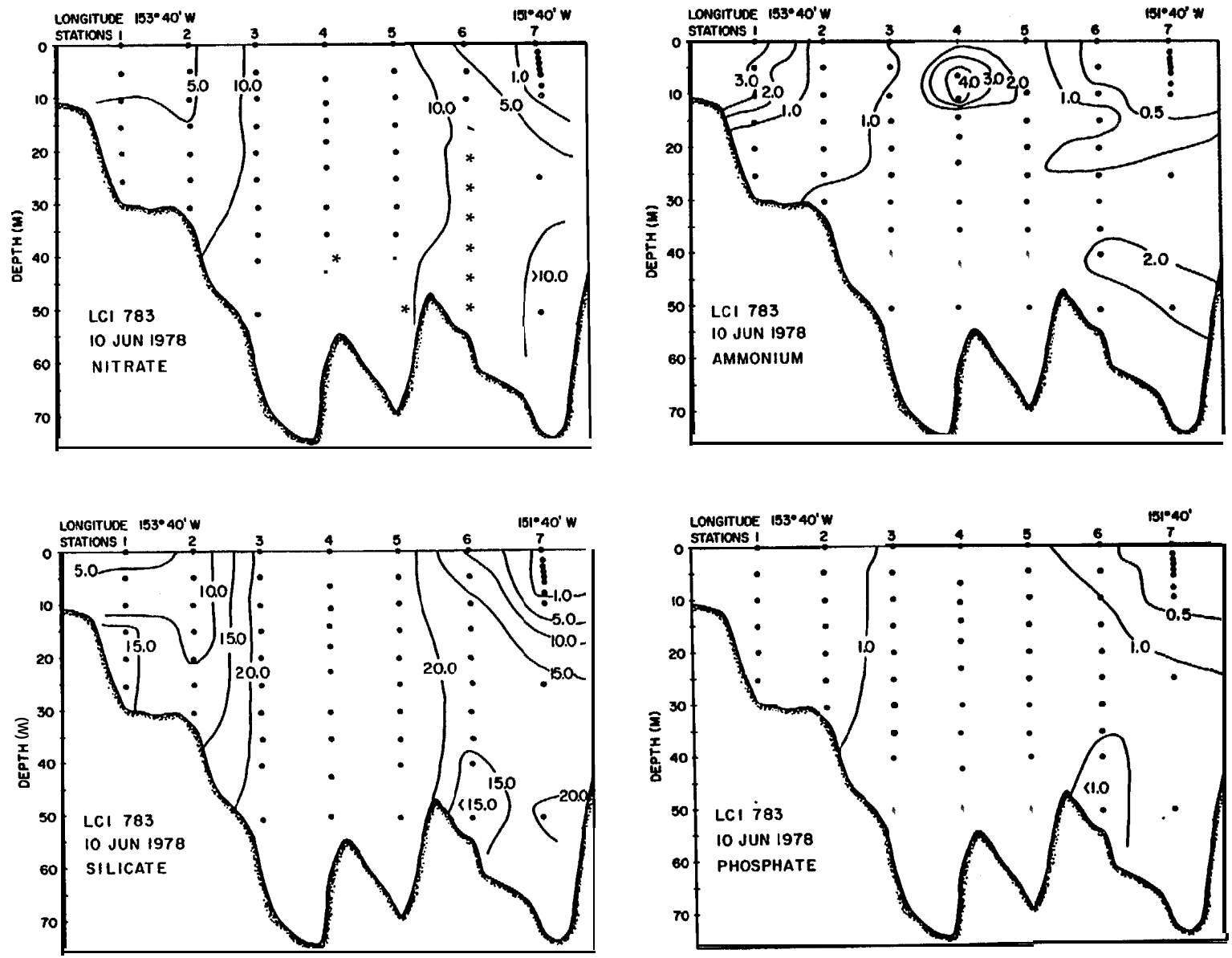

Figure A-6. Nutrients, 10 June.

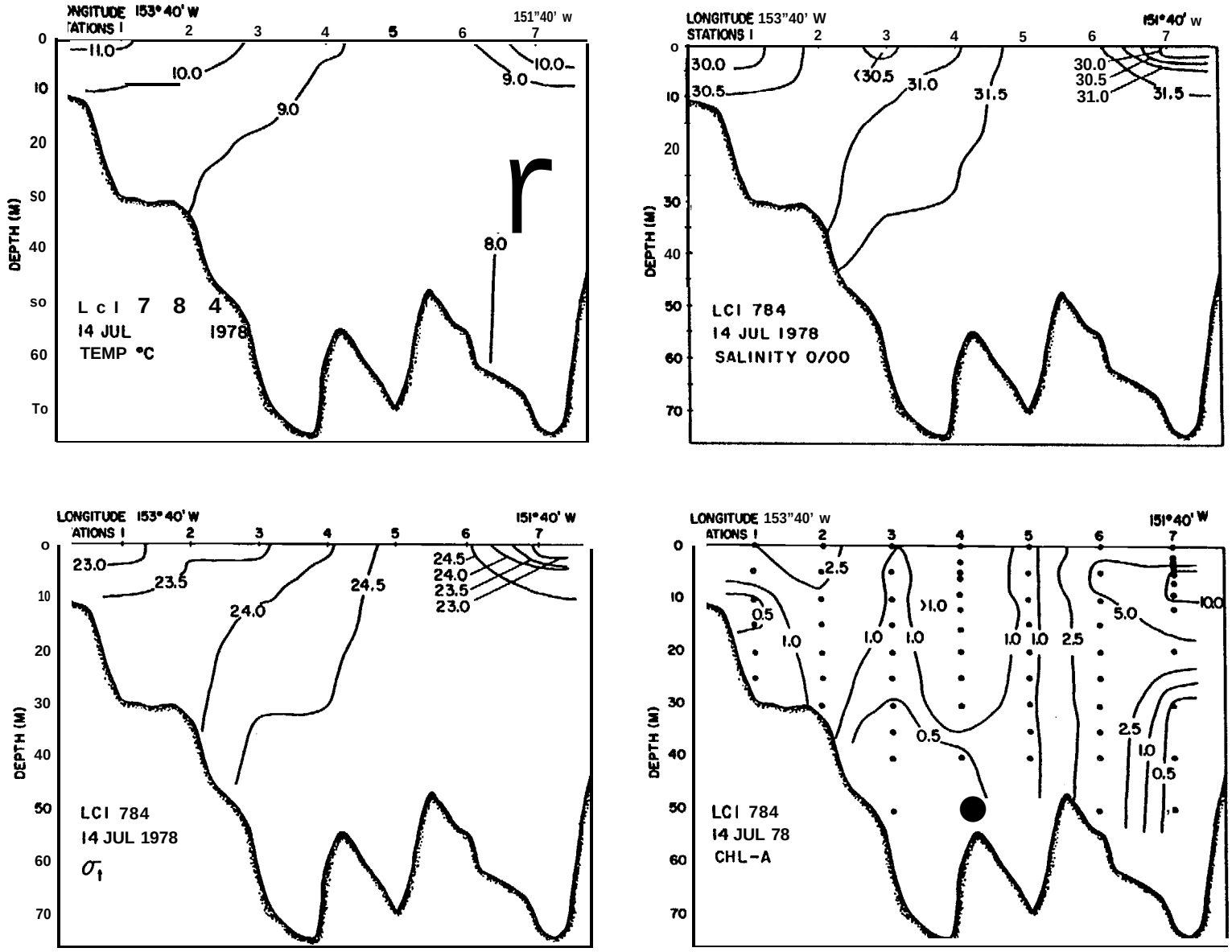

Figure A-7. Temperature, salinity, sigma-t, and chlorophyll-a, 14 July.

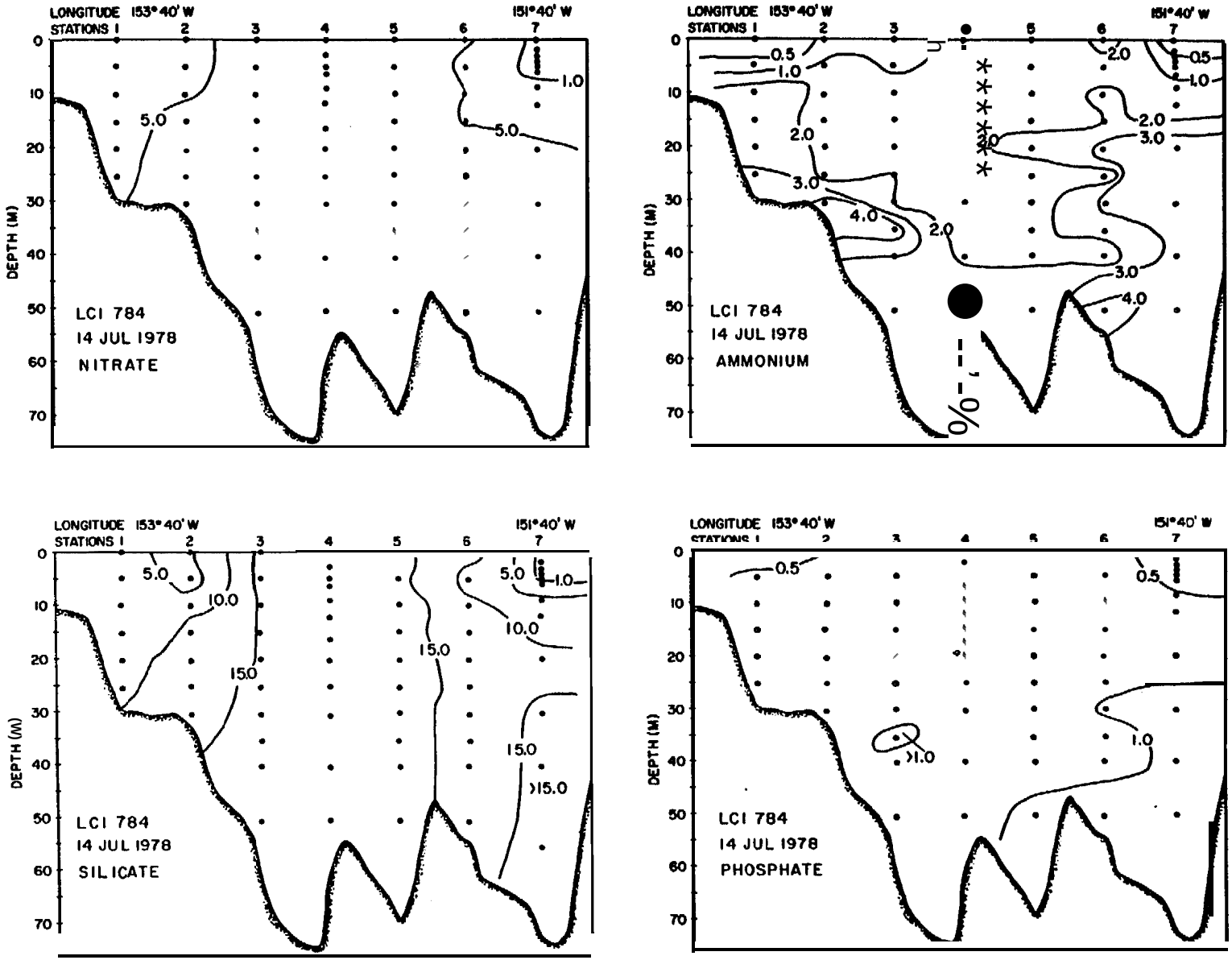

Figure A-8. Nutrients, 4 July.

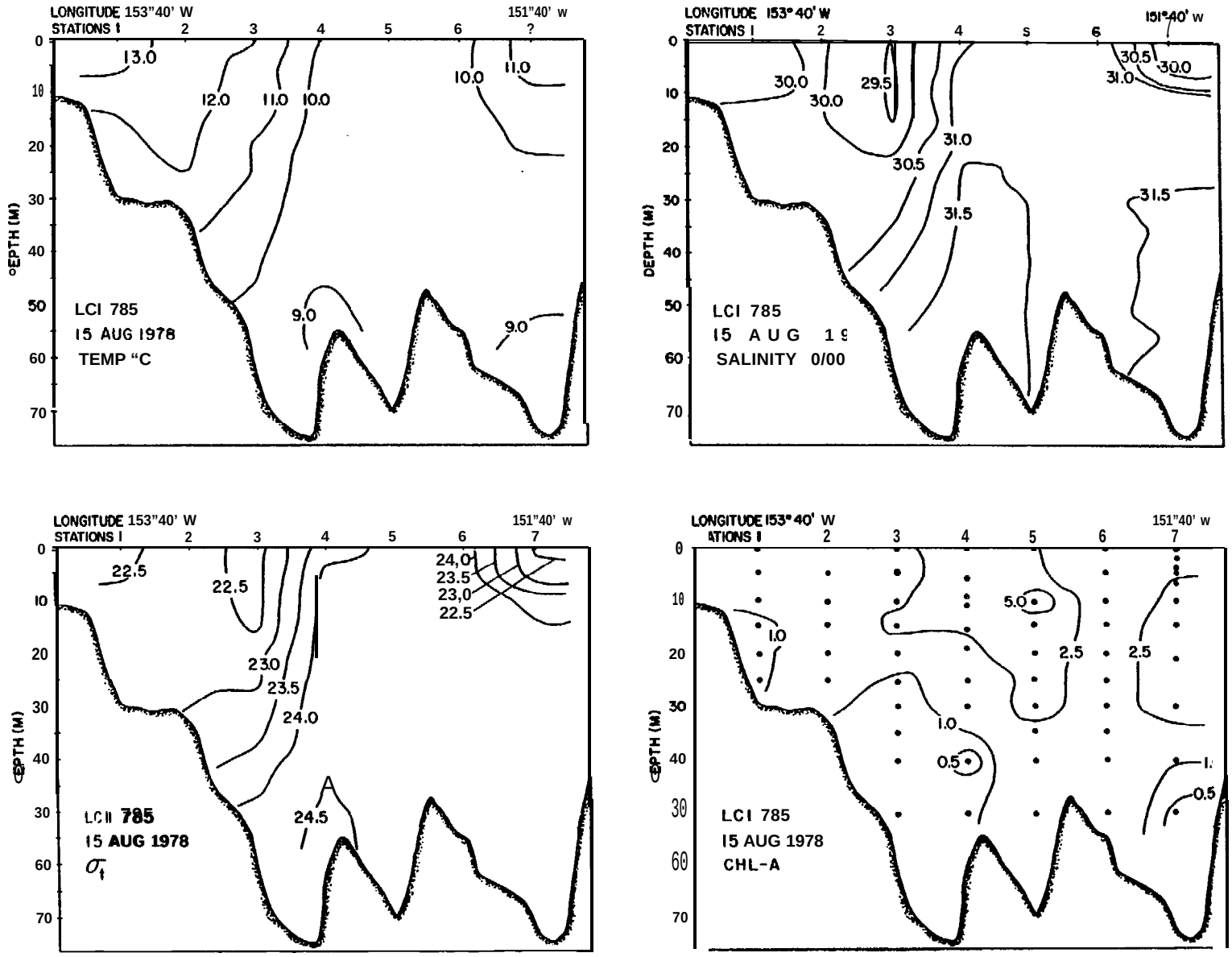

Figure A-9. Temperature, salinity, sigma-t, and chlorophyll-a, 15 August.

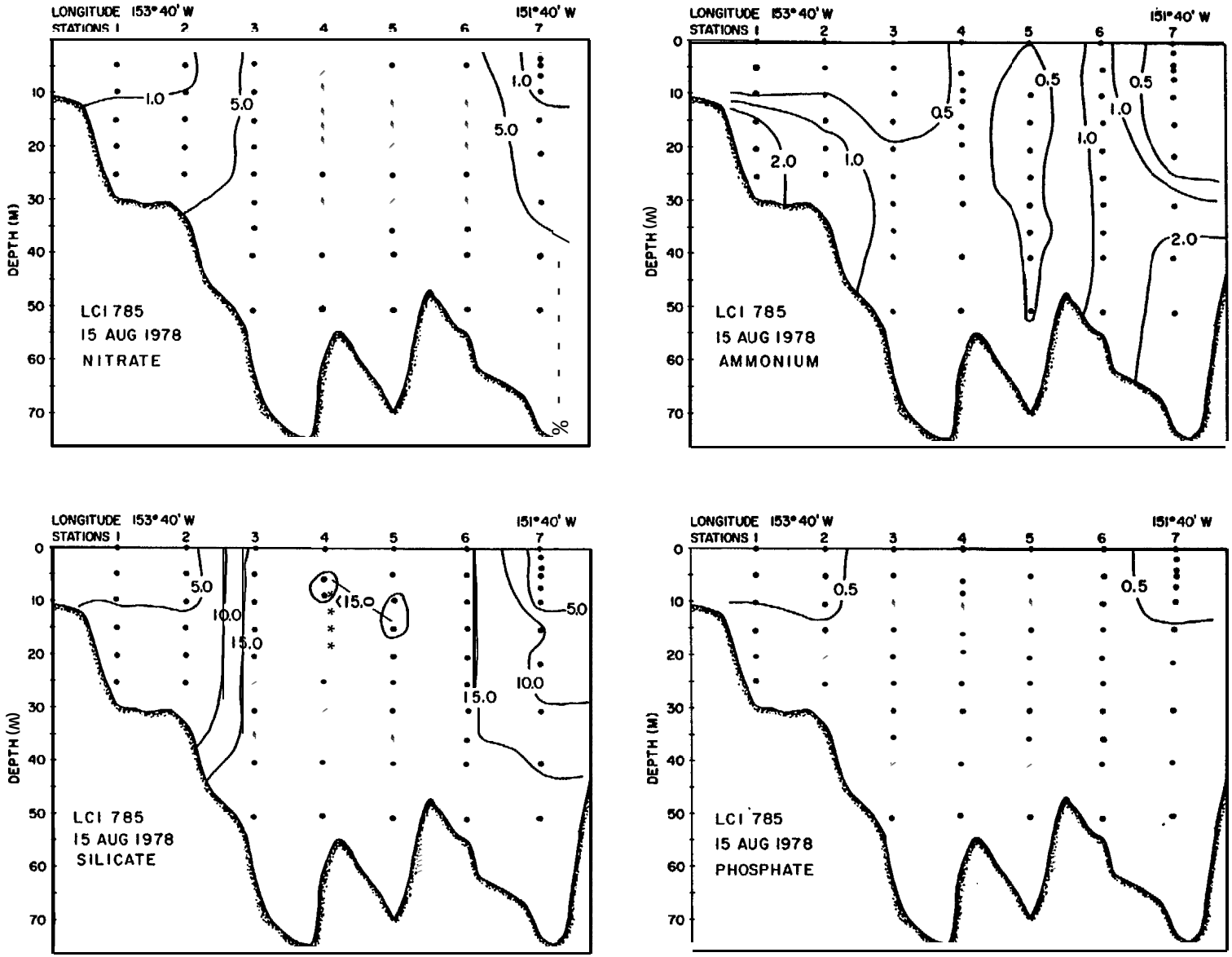

Figure A-10. Nutrients, 15 August.